

Description

The present invention relates to Pulse Code Modulation (PCM) transmission techniques. It is particularly concerned with the problem of minimising the demands such techniques put upon the transmitter in the context of a system such as a passive optical network used for telephony.

In standard forms of coding for Pulse Code Modulation, such as the coding scheme recommended by CCITT for telephony, an analogue signal is divided into a number of quantisation levels (256 in the case of 8-bit coding) and each quantisation level assigned a binary codeword. The quantisation levels may be uniformly distributed over the amplitude range of the signal or alternatively a logarithmic distribution may be used. In either case the binary codewords are assigned sequentially to the quantisation levels so that, for example, in the CCITT 8-bit coding scheme quantisation levels 130, 131 and 132 are assigned binary codewords 1000 0001, 1000 00010 and 1000 0011. The first (i.e. most significant) bit of the codeword is used to denote the sign of the quantisation level.

It is known from IBM Technical Disclosure Bulletin, Vol. 28, No. 10, March 1986, pages 4440, 4441 to use a group encoding method to reduce the power requirement of infra-red light emitting diodes. The method encodes an incoming data stream in the form of 4-bit data groups into 5-bit groups. Because of the inherent redundancy 4-bit groups having more than two ON bits (logic ones) can be encoded into 5-bit groups having only two ON bits.

Statistical encoding is disclosed in "Data Compression", 1983, John Wiley & Sons, Chichester, GB in which short codes are used to represent frequently occurring characters or groups of characters while longer codes are used to represent less frequently encountered characters and groups of characters whereby the average code length of encoded data is minimised. Because such coding schemes have variable length codewords, it is not possible to know where the boundaries of the codewords are and this places a constraint on the codes that can be used. Moreover, in, for example, Huffman coding for the English language the coding scheme in each of the groups of variable length codewords is sequential coding.

It is known from Hölzler and Holzwarth, "Pulstechnik", Volume 1, pages 286 and 287, to code an analogue signal for transmission using pulse position modulation. For eight quantisation levels, the quantising periods are divided into eight equal segments and for each period a single pulse is transmitted in the segment corresponding to the quantised value of the signal. Although the transmission of a single pulse per period in a pulse position modulation scheme appears to be equivalent to the serial transmission of an 8-bit codeword containing a single ON bit, it will be appreciated that the similarity of pulse position modulation and pulse code modulation goes thus far and no further.

According to a first aspect of the present invention a method of processing a signal having a non-uniform amplitude probability density for transmission in pulse code modulated form comprising quantising the signal and coding the quantised signal using a non-sequential coding scheme in which equal length binary codewords for the quantisation levels are chosen in accordance with the probability of the quantisation levels and the number of ON bits in the codeword such that quantisation levels of higher probability are assigned codewords with fewer ON than quantisation levels of lower probability.

The present invention provides a coding scheme which minimises the power required to transmit signals such as speech or music which have non-uniform amplitude probability densities. The amplitude probability distribution of speech, for example, peaks around zero amplitude and decreases with increasing amplitude. Similarly after quantisation the most probable quantisation levels are those corresponding to the lowest amplitudes and the quantisation levels corresponding to increasing amplitudes have decreasing probabilities. The codeword which consumes the least power is all zeros, 0000 0000 in 8-bit coding, and that which consumes the most power is all ones, 1111 1111. Since the most likely quantisation level, i.e. zero for speech, will over a period of time occur most frequently it is allocated the codeword 0000 0000. The nearest eight levels are the next most likely and are therefore allocated codewords having just a single ON bit, i.e. words taken from the set 0000 0001, 0000 0010, 0000 0100, ... 1000 0000. Such a coding scheme by matching the codewords requiring least power to the most frequently occurring quantisation levels effects a marked reduction in the time-averaged power required for transmission of the signal.

The advantages of using a method in accordance with the present invention are found to be particularly great for optical systems using sources such as semiconductor diode lasers. By enabling the transmitter in such a system to run cooler and place less demand on the power supply a significant increase in transmitter reliability is obtained. A further advantage is that with a method in accordance with the present invention near-end cross-talk levels are reduced. Inter symbol interference (ISI) is also reduced.

According to a second aspect of the present invention an optical network including a central station having a master clock source and being connected to a remote station including signal processing means

arranged to quantise a signal having a non-uniform amplitude probability density for return transmission to the central station, the signal processing means being also arranged to code the quantised signal into a pulse code modulated form for transmission in accordance with a non-sequential coding scheme in which equal length binary codewords for the quantisation levels are chosen in accordance with the probability of the quantisation levels and the number of ON bits in the codeword such that quantisation levels of higher probability are assigned codewords with fewer ON bits than quantisation levels of lower probability.

In transmission from the central station to a remote station without its own clock it is necessary to code the signal using a conventional line code which allows a synchronous clock to be recovered at the remote station. However for the return direction of transmission there is need to re-transmit the clock since the master clock, with an appropriate phase shift, can be used to synchronise the regeneration of the signal received at the central station. Accordingly the processing of a signal for transmission along the return path to the central station is particularly appropriate for the use of a method in accordance with the first aspect of the present invention since the coding may be chosen simply to minimise the power requirements and there is no need for a conventional line code. Since a typical network will include many remote stations for each central station the advantages of a method which increases the reliability of the transmitters of the remote stations are particularly great.

The present invention is now described in detail with reference to the accompanying drawing in which: Figures 1A and 1B are graphs illustrating probability distributions for signal amplitudes and the corresponding function for quantisation levels;

Figure 2 is a table listing a prior art coding scheme and a coding scheme in the accordance with the present invention; and,

Figure 3 is a diagram illustrating a network in accordance with the second aspect of the present invention.

A signal such as speech or music having a non-uniform probability distribution is quantised using conventional methods and a binary codeword assigned to each quantisation level. The codewords are transmitted in pulse code modulated forms using ON/OFF keying in a non-return-to-zero (NRZ) format.

In the preferred embodiment 8-bit codewords are used to code a total of 256 different quantisation levels. The binary codewords are grouped into subsets according to the number of ON bits, i.e. ones rather than zeros, present. An 8-bit binary code set has 9 subsets, ranging from all zeros to all ones. The number of members of each subset as given by the permutation formula is shown in table 1 below where (1/8) denotes the subset of codewords having only one of the 8 bits equal to unity (2/8) denotes the subset of codewords having only two of the 8 bits equal to unity and so on.

TABLE 1

SUBSET	NUMBER OF CODEWORDS
(0000 0000)	1
(1/8)	8
(2/8)	28
(3/8)	56
(4/8)	70
(5/8)	56
(6/8)	28
(7/8)	8
(1111 1111)	1

The amplitude probability distribution of speech which is discussed in more detail below, is such that the most frequently occurring quantisation level is zero. The codeword requiring minimum power, 0000 0000 is therefore allocated to this level. The 8 codewords in the subset (1/8) are then assigned to the next most frequently occurring 8 quantisation levels and so on up to the subset (1111 1111), the codeword requiring the greatest power which is assigned to the quantisation level of lowest probability.

The 256 quantisation levels may be uniformly distributed over the amplitude range of interest or, in the case of the A law companding commonly used for speech a logarithmic distribution may be used which matches more closely the sensitivity of the ear. The piecewise linear approximation to the A law as recommended by the CCITT is shown in figure 1A for input amplitudes in the range 0-1 V. A symmetrical function is used for negative input levels.

The amplitude probability distribution of speech is represented by a gamma function (also shown in figure 1A.)

$$P(x) = (k/2\Gamma(l)) (kx)^{l-1} e^{-kx}$$

where x is the instantaneous r.m.s. amplitude and l is a parameter and $k = [l(l+1)]^{1/2}$. This function which peaks around 0 and is small at high levels, is discussed in detail in the text "Telecommunications By Speech", author D L Richards, published by Butterworth. If uniform quantising is used for speech then the probability distribution function (PDF) given in figure 1A would also represent the probability of any quantisation interval occurring, and appropriate code allocations could readily be made. For the case of particular interest where companding is used the PDF for the various quantisation intervals must be derived by considering the mapping of the gamma function through the piecewise linear approximation to the A law. For simplicity this mapping has also been performed graphically for each linear segment and the resultant histogram is shown in figure 1B. This PDF also peaks at low input levels. There is a secondary maximum at input amplitudes around ± 0.5 which could affect the optimum choice of codewords so that the allocations for uniform and companded quantising would differ. However, since the peak is small and its position would vary for loud and quiet speakers, it may conveniently be neglected.

Since both uniform and companded quantising give rise to PDFs which peak at low input amplitudes the codeword allocations range from the minimum power codes near zero through to the highest power codes (7/8) and (1111 1111) at the extremes.

The table of Figure 2 shows one possible power minimising coding scheme employing symmetry for a selection of 256 quantising levels. This is compared with the present CCITT recommendations for speech transmission. Gaps are left in the table to separate the subsets of numbers of ON bits per word. These subsets are divided between the positive and negative quantisation levels which split at quantisation levels 128/129. Dotted lines show where the table is incomplete.

When no speech is present at the input to the encoder, random noise will cause the quantiser to waver between levels 128 and 129, assuming the noise is at a low level. Under this condition it is advantageous to represent both levels by the codeword 0000 0000. This then prevents power being transmitted during, for example, the pauses while someone using a telephone system is listening to received speech. To avoid ambiguity at the decoder the same effect could be achieved by applying a DC offset equal to half a quantising interval in the positive sense at the input to the encoder. There is then no ambiguity at the encoder output when no signal is present at the input.

An optical network employing the method of the present invention is shown diagrammatically in figure 3. A time division multiple access (TDMA) network includes a central station 1 linked to remote stations 2. The central station includes a master clock 3, a transceiver 4 which includes an optical source such as a semiconductor diode laser and signal processing means, and a passive power divider 5. Digital signals are transmitted from the central station 1 to the remote stations 2 using conventional line coding techniques. Each remote station extracts a clock from the incoming signal which it uses to synchronously demultiplex the channels it is to receive. In the return direction a time division multiplex is formed by interleaving data from each of the remote stations 2. For the return direction of transmission there is no need to retransmit the clock since the network is now synchronous. The transceivers 6 of the remote stations 2 therefore include in addition to optical sources signal processing means arranged to operate in accordance with the method of the first aspect of this invention. The signal for return transmission is encoded using a power-minimising coding scheme and without a conventional line code. As a result the optical source in each remote station 2 runs cooler and places less demand upon the power supply. This method is found to increase significantly the reliability of the remote stations and so to enhance that of the network as a whole.

Claims

1. A method of processing a signal for an optical network, the signal having a non-uniform amplitude probability density for transmission in pulse code modulated form comprising quantising the signal and coding the quantised signal using a non-sequential coding scheme in which equal length binary codewords for the quantisation levels are chosen in accordance with the probability of the quantisation levels and the number of ON bits in the codeword such that quantisation levels of higher probability are assigned codewords with fewer ON bits than quantisation levels of lower probability.
2. A method according to claim 1, in which the probability density decreases with increasing amplitude and the one positive and one negative quantisation levels of least amplitude are both assigned



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Claims

1. A method of processing a signal for an optical network, the signal having a non-uniform amplitude probability density for transmission in pulse code modulated form comprising quantising the signal and coding the quantised signal using a non-sequential coding scheme in which equal length binary codewords for the quantisation levels are chosen in accordance with the probability of the quantisation levels and the number of ON bits in the codeword such that quantisation levels of higher probability are assigned codewords with fewer ON bits than quantisation levels of lower probability.
2. A method according to claim 1, in which the probability density decreases with increasing amplitude and the one positive and one negative quantisation levels of least amplitude are both assigned



codewords having no ON Bits.

3. A method according to claim 1 or 2, in which the coded signal is transmitted using a semiconductor optical source.
- 5 4. A method according to any one of claims 1 to 3, in which the number of bits in a codeword is equal to the number of bits in a timeslot of the transmission system.
- 10 5. A method according to any one of claims 1 to 4, in which the number of quantisation levels is 2 to the power n, where n is the number of bits in a codeword.
- 15 6. An optical network including a central station having a master clock source and being connected to a remote station including signal processing means arranged to quantise a signal having a non-uniform amplitude probability density for return transmission to the central station, the signal processing means being also arranged to code the quantised signal into a pulse code modulated form for transmission in accordance with a non-sequential coding scheme in which equal length binary codewords for the quantisation levels are chosen in accordance with the probability of the quantisation levels and the number of ON bits in the codeword such that quantisation levels of higher probability are assigned codewords with fewer ON bits than quantisation levels of lower probability.
- 20 7. A network according to claim 6, wherein, for return transmission of signals for which the probability density decreases with increasing amplitude, the signal processing means is arranged to code quantised signals having the one positive and one negative quantisation levels of least amplitude with a codeword having no ON bits.
- 25 8. A network according to claim 6 or 7, wherein the number of bits in a codeword is equal to the number of bits in a timeslot of the transmission system.
- 30 9. A network according to any one of claims 6 to 8, wherein the number of quantisation levels is 2 to the power n, where n is the number of bits in a codeword.

Patentansprüche

- 35 1. Verfahren zum Verarbeiten eines Signals für ein optisches Netzwerk, wobei das Signal eine nicht gleichmäßige Amplitudenwahrscheinlichkeitsdichte aufweist, zur Übertragung in Pulscode-modulierter Form, wobei das Verfahren aufweist:
Quantisieren des Signals und Codieren des quantisierten Signals unter Verwendung eines nicht-sequentiellen Codierschemas, in dem binäre Code-Wörter gleicher Länge für die Quantisierungspegel gewählt werden in Übereinstimmung mit der Wahrscheinlichkeit der Quantisierungspegel und der
40 Anzahl der EIN-Bits in dem Code-Wort, so daß Quantisierungspegel höherer Wahrscheinlichkeit an Code-Wörter zugewiesen werden mit weniger EIN-Bits als Quantisierungspegel niedrigerer Wahrscheinlichkeit.
- 45 2. Verfahren gemäß Anspruch 1, bei dem die Wahrscheinlichkeitsdichte mit zunehmender Amplitude abnimmt und der eine positive und eine negative Quantisierungspegel einer geringsten Amplitude werden beide an Code-Wörter zugewiesen, die keine EIN-Bits aufweisen.
3. Verfahren gemäß Anspruch 1 oder 2, bei dem das codierte Signal unter Verwendung einer optischen Quelle aus Halbleitern übertragen wird.
- 50 4. Verfahren gemäß einem der Ansprüche 1 bis 3, bei dem die Anzahl der Bits in einem Code-Wort gleich der Anzahl der Bits in einem Zeitschlitz des Übertragungssystems ist.
- 55 5. Verfahren gemäß einem der Ansprüche 1 bis 4, bei dem die Anzahl der Quantisierungspegel gleich zwei hoch n ist, wobei n die Anzahl der Bits in einem Code-Wort ist.
6. Optisches Netzwerk, das eine Zentralstation aufweist, die eine Haupttaktgeberquelle aufweist und mit einer entfernten Station verbunden ist, die eine Signalverarbeitungseinrichtung aufweist, die angeordnet



- ist, um ein Signal mit einer nicht-gleichförmigen Amplitudenwahrscheinlichkeitsdichte zu quantisieren, zur Rückübertragung an die Zentralstation` wobei die Signalverarbeitungseinrichtung auch angeordnet ist, um das quantisierte Signal in einer Pulscode-modulierten Form zu codieren zur Übertragung in Übereinstimmung mit einem nicht-sequentiellen Codierschema, bei dem binäre Code-Wörter gleicher Länge für die Quantisierungspegel gewählt sind in Übereinstimmung mit der Wahrscheinlichkeit der Quantisierungspegel und die Anzahl der EIN-Bits in dem Code-Wort so, daß Quantisierungspegel höherer Wahrscheinlichkeit an Code-Wörter mit weniger EIN-Bits zugewiesen sind als Quantisierungspegel niedrigerer Wahrscheinlichkeit.
7. Netzwerk gemäß Anspruch 6, wobei zur Rückübertragung von Signalen, für die die Wahrscheinlichkeitsdichte mit zunehmender Amplitude abnimmt, die Signalverarbeitungseinrichtung angeordnet ist, um quantisierte Signale zu codieren, die einen positiven und einen negativen Quantisierungspegel geringster Amplitude aufweisen, mit einem Code-Wort, das keine EIN-Bits aufweist.
8. Netzwerk gemäß Anspruch 6 oder 7, wobei die Anzahl von Bits in einem Code-Wort gleich der Anzahl von Bits in einem Zeitschlitz des Übertragungssystems ist.
9. Netzwerk gemäß einem der Ansprüche 6 oder 8, wobei die Anzahl von Quantisierungspegeln zwei hoch n ist, wobei n die Anzahl von Bits in einem Code-Wort ist.

Revendications

1. Un procédé de traitement d'un signal destiné à un réseau optique en vue d'une transmission sous forme modulée à code pulsé, la densité de probabilité d'amplitude du signal étant non uniforme, comprenant une quantification du signal et un codage du signal quantifié en utilisant un schéma de codage non séquentiel dans lequel des mots de code binaires de longueurs égales sont choisis, pour les niveaux de quantification, selon la probabilité des niveaux de quantification et le nombre de bits EN FONCTION dans le mode de code est tel qu'il est assigné, à des niveaux de quantité de probabilité plus élevés, des mots de code où le nombre de bits EN FONCTION est moindre que dans le cas des niveaux de quantification à probabilité plus faible.
2. Un procédé selon la revendication 1, dans lequel la densité de probabilité décroît lorsque l'amplitude croît et il est assigné des mots de code n'ayant aucun bit EN FONCTION aux deux niveaux de quantification, l'un positif et l'autre négatif, de moindre amplitude.
3. Un procédé selon la revendication 1 ou 2, dans lequel le signal codé est transmis en utilisant une source optique à semi-conducteur.
4. Un procédé selon l'une quelconque des revendications 1 à 3 dans lequel le nombre de bits d'un mot de code est égal au nombre de bits d'une tranche de temps du système de transmission.
5. Un procédé selon l'une quelconque des revendications 1 à 4, dans lequel le nombre de niveaux de quantification est 2 à la puissance n , où n est le nombre de bits d'un mot de code.
6. Un réseau optique incluant une station centrale pourvue d'une source d'horloge centrale et reliée à une station située à distance incluant un moyen de traitement de signaux agencé pour quantifier un signal dont la densité de probabilité d'amplitude est non uniforme en vue d'une transmission en retour vers la station centrale, le moyen de traitement de signaux étant également agencé pour coder le signal quantifié sous une forme modulée par impulsions codées en vue d'une transmission selon un schéma de codage non séquentiel dans lequel des mots de code binaires de longueurs égales sont choisis, pour les niveaux de quantification, selon la probabilité des niveaux de quantification et le nombre de bits EN FONCTION dans le mode de code est tel qu'il est assigné, à des niveaux de quantité de probabilité plus élevés, des mots de code où le nombre de bits EN FONCTION est moindre que dans le cas des niveaux de quantification à probabilité plus faible.
7. Un réseau selon la revendication 6 dans lequel le moyen de traitement de signaux est agencé de manière à coder au moyen d'un mot de code n'ayant aucun bit EN FONCTION les deux niveaux de quantification, l'un positif et l'autre négatif, de moindre amplitude, en vue de transmettre en retour des



signaux pour lesquels la densité de probabilité décroît lorsque l'amplitude croît.

8. Un réseau selon la revendication 6 ou 7, dans lequel le nombre de bits d'un mot de code est égal au nombre de bits d'une tranche de temps du système de transmission.
9. Un réseau selon l'une quelconque des revendications 6 à 8, dans lequel le nombre de niveaux de quantification est 2 à la puissance n , où n est le nombre de bits d'un mot de code.