

# **Digital Modulation and Demodulation Technique for Reliable Wireless (Both RF And IR) And Wired High Bandwidth Data Transmission**

## **Background of the Invention**

### **Field of the Invention**

- 5    [0001]        This invention relates to transmission and reception of signals. More particularly, this invention relates to the encoding and modulation of transmission signals with digital data and the demodulation and decoding of received signals corrupted by channel induced intersymbol interference.

### **Description of Related Art**

- 10   [0002]        In the transmission and reception of digital data, channel induced intersymbol interference is the arrival of multiple copies of a transmitted signal that causes the information from one segment of information to corrupt a subsequent segment of information. The multiple copies of the transmitted signals occur generally because of reflections of the transmitted signals within  
15        the environment.

- [0003]        The level of the reflection determines the level of degradation of the signal received and the probability of the intersymbol interference causing errors in the reception of the signals. Also, the amount of time required for the reflections to

transit from the transmitter to the reflection point and thence to the receiver further determines the quantity of intersymbol interference.

[0004] Refer now to Fig. 1 for a discussion of channel induced intersymbol interference in a wireless radio frequency (RF) transmission. In this instance the transmitter **5** is connected to the antenna **10**, which radiates an RF signal. Even though the RF signal emanates from the antenna **10** as a contiguous wavefront, it is shown as three separate wavefronts **35**, **40**, and **50**. The wavefront **35** is travels through the atmosphere in a direct path. The wavefront **40** travels through the atmosphere and is reflected from a landmass **30** such as mountains and hills. The reflected wavefront **45** then arrives at the antenna **15**. The wavefront **50** travels through the atmosphere and is reflected by buildings **25** of a metropolitan area. The reflected wavefront **55**, likewise, then arrives at the antenna **15**.

[0005] The antenna **15** is connected to the receiver **20**. The receiver acquires the transmitted signal and recovers the information modulated within the RF signal. It is apparent that the wavefront **35** travels the most direct route from the transmitting antenna **10** to the receiving antenna **15**. The reflected wavefronts **45** and **55**, on the other hand, arrive at the antenna **15** at some time later than the wavefront **35**. If the amplitude of the reflected wavefronts is larger than the environmental noise, the receiver will acquire the reflected wavefronts **45** and **55**

and be indistinguishable from the wavefront 35, except that they will be delayed in time.

[0006] Refer now to Fig. 2 for a discussion of the channel induced intersymbol interference within a wireless RF data communication system. The digital data 105 and its synchronizing clock 100 is the input signal to the transmitter 5 of Fig. 1. A common method of modulating the RF signal with the digital data 105 is frequency shift keying (FSK). In frequency shift keying, the voltage level of the digital data representing a digit having a binary 0 causes the RF signal to have a first frequency  $f_0$  135 and the digit having a binary 1 causes the RF signal to have a second frequency  $f_1$  140.

[0007] The transmitter 5 transmits the RF signal 110 from the antenna 10 as described above. The RF signal transits the multiple paths as described with each signal being delayed in time. The direct RF signal  $\lambda_1$  115 arrives at the antenna after a delay  $\delta_1$  145. The reflected RF signal  $\lambda_2$  120 arrives at the antenna after a delay  $\delta_2$  150. The reflected RF signal  $\lambda_3$  125 arrives at the antenna after a delay  $\delta_3$  155.

[0008] The direct RF signal  $\lambda_1$  115 and the reflected RF signals  $\lambda_2$  120 and  $\lambda_3$  125 are superimposed upon each other at the antenna and transferred to the receiver 20. The receiver 20 employs superheterodyne techniques to extract the digital data from the differences in frequency that defines the digital data. The

data message **130** should change from the binary zero to the binary 1 at the time **170**. However, the delayed reflected signals  $\lambda_2$  **120** and  $\lambda_3$  **125** interfere with the direct received signal **115** and cause an uncertainty **160** of the digital data. The digital data may remain at the binary 0 and is not definitely changed until the time **175**. The magnitude of the delayed reflected signals  $\lambda_2$  **120** and  $\lambda_3$  **125** determines the impact of this intersymbol interference. Similarly, the data message **130** should change from the binary 1 to the binary 0 at the time **10**, however, the interference from the delayed reflected signals  $\lambda_2$  **120** and  $\lambda_3$  **125** might cause the data message **130** to remain at the binary 1 until the time **185**. This uncertainty time **165** may cause a misinterpretation of the digital data.

[0009] Similar channel induced intersymbol interference can occur in wireless infrared light transmission as illustrated in Fig. 3. In this case the transmitter **205** and the receiver **220** are generally enclosed within a room **200**. The transmitter **205** excites the light emitting diode (LED) to emit infrared light. A typical type of transmission is on-off-keying (OOK), where the LED is excited for data having a binary one and turned off for data having a binary zero. The light is transmitted to a photodiode **215**. The photodiode **215** is connected to the receiver **220**, which recovers the received light signal and demodulates the received signal to extract the transmitted information.

[0010] The light signal as transmitted from the LED **210** is a contiguous wavefront, but for illustration it is shown as three separate wavefronts **235**, **240**,

and 250. The wavefront 235 represents the portion of the light signal that travels directly to the photodiode 215. The wavefronts 240 and 250 are transmitted toward the sidewalls of the room 200 and the wavefronts 246 and 255 are reflected to the sidewalls to the photodiode 215. The reflected wavefronts 246 and 255 travel a longer distance through the room 200 to arrive at the photodiode 215 and thus interfere with the wavefront 235 that arrive earlier.

[0011] Referring to Fig. 4 for a discussion of the modulation of the light signal as transmitted from the transmitter 205 of Fig. 3. The data clock 300 has the frequency rate that the digital data message is gated within the transmitter 210. The modulation clock (PPM CLK 305) that is used to generate the four-pulse position modulated signal of the transmitted signal 310. Each time slot t1, t2, t3, t4 is divided into four sub-increments s1, s2, s3, s4. One sub-increment s1, s2, s3, or s4 is set to a binary one, in this representation, to represent a two digit binary number. Since only one sub-segment may be occupied for any one time slot t1, t2, t3, t4, the coding can only represent the four possible combinations of the two digit binary numbers. The four-pulse position modulated signal of the data message illustrates the modulation of the four possible binary digit combinations of the dual-bit data and is explained as follows:

| Time Slot | Dual-Bit Code | PPM Encoding |
|-----------|---------------|--------------|
| t1        | 00            | 1000         |
| t2        | 01            | 0100         |

|           |           |             |
|-----------|-----------|-------------|
| <b>t3</b> | <b>10</b> | <b>0010</b> |
| <b>t4</b> | <b>11</b> | <b>0001</b> |

[0012] The pulse positioned modulated signal **310** is transmitted by activation of the LED **210**. The direct light signal  $\lambda_1$  **320** arrives at the photodiode **215** after a delay  $\delta_1$  **340**. The reflected light signal  $\lambda_2$  **325** arrives at the photodiode **215** after a delay  $\delta_2$  **345**. The reflected light signal  $\lambda_3$  **330** arrives at the photodiode **215** after a delay  $\delta_3$  **350**.

[0013] The direct light signal  $\lambda_1$  **320** and the reflected light signals  $\lambda_2$  **325** and  $\lambda_3$  **330** are superimposed upon each other at the photodiode **215** and transferred to the receiver **220**. The receiver **220** recovers the pulse positioned data message **335**. The pulse positioned data **335** changes from the voltage level of the binary zero to the voltage level of the binary one after the delay  $\delta_1$  **340**. However, the delay  $\delta_2$  **345** and  $\delta_3$  **350** of the reflected signals  $\lambda_2$  **325** and  $\lambda_3$  **330** causes the photodiode to detect the binary one for a time longer than the length of a sub-increment  $s_1, s_2, s_3, s_4$  of a time slot **t1, t2, t3, or t4**. The magnitude of the reflection maybe insufficient to consistently determine this uncertainty time **355**. Further, if two symbols such as a **11** followed by a **00** are transmitted the detection of the binary one extending beyond the sub-increment  $s_1, s_2, s_3, s_4$  of a time slot **t1, t2, t3, or t4** now interferes with a subsequent symbol. The severity of the channel induced intersymbol interference prevents the extension of the

bandwidth of communication system beyond the ability of the communication to reliably detect and recover the received data message.

[0014] U. S. Patent 6,169,765 (Holcombe) describes an output signal pulse width error correction circuit and method wherein errors in a data signal conforming to a communications protocol having a prescribed duty cycle are corrected by  
5 monitoring a duty cycle of the data signal, comparing the duty cycle to a duty cycle reference voltage corresponding to the prescribed duty cycle, and adjusting a pulse width of the data signal to conform to the prescribed duty cycle of the protocol.

10 [0015] U. S. Patent 5,394,410 (Chen) explains a technique for encoding data for serial transmission and the correlative technique for decoding the transmitted data.

[0016] U. S. Patent 5,892,796 (Rypinski) illustrates frame format and method for adaptive equalization within an integrated services wireless local area network to  
15 prevent fading and intersymbol interference due multiple path radio propagation.

[0017] U. S. Patent 6,118,567 (Alameh, et al.) teaches a waveform encoding method and device provide for generating/receiving a power efficient binary intensity modulated optical data signal from a binary source signal which minimizes a time between adjacent pulse transitions and maximizes a pulse peak  
20 amplitude for transmission over a low-power wireless infrared link.

[0018] "Efficient Reconstruction of Sequences," Levenshtein, et al., IEEE Transactions on Information Theory, Jan. 2001, Volume: 47, Issue: 1, pp. 2 - 22 introduces and provides solutions for problems of efficient reconstruction of an unknown sequence from its versions distorted by errors of a certain type.

5 [0019] "Spread-Response Precoding for Communication Over Fading Channels," Wornell, IEEE Transactions on Information Theory, March 1996, Volume: 42, Issue: 2, pp. 488 - 501 presents "spread-response precoding" to effectively transform an arbitrary Rayleigh fading channel into a nonfading, simple white marginally Gaussian noise channel.

10 [0020] "Linear Complexity Of A Sequence Obtained From A Periodic Sequence By Either Substituting, Inserting, Or Deleting K Symbols Within One Period," Jiang et al., IEEE Transactions on Information Theory, May 2000, Volume: 46, Issue: 3, pp. 1174 - 1177 provides a unified derivation of the bounds of the linear complexity for a sequence obtained from a periodic sequence over  $GF(q)$  by  
15 either substituting, inserting, or deleting k symbols within one period.

[0021] "On The Synchronizability And Detectability Of Random PPM Sequences," Georgiades, IEEE Transactions on Information Theory, Jan. 1989, Volume: 35, Issue: 1, pp. 146 - 156, investigates the problem of synchronization and detection of random pulse-position modulation (PPM) sequences under the  
20 assumption of perfect slot synchronization. Bounds on the symbol error probability and the probability of false synchronization that indicate the existence

of a severe performance floor are derived. A way to eliminate the performance floor is suggested by inserting 'special' PPM symbols in the random data stream.

### **Summary of the Invention**

[0022] An object of this invention is to provide a communication system where  
5 pulse positioned modulated data signals is compensated for channel induced intersymbol interference.

[0023] An object of this invention is to extract pulse positioned encoded data from a received signal corrupted with channel induced intersymbol interference.

[0024] To accomplish at least one of these objects and other objects a  
10 communication system has a transmitter and a receiver. The transmitter transmits a signal containing pulse positioned modulated and compensated data symbols. The receiver acquires the signal containing the pulse positioned modulated data symbols, recovers the data symbols, and extracts the data.

[0025] The transmitter includes a modulation apparatus connected to receive  
15 data and convert the data to pulse positioned modulated data symbols, the pulse positioned modulated data symbols encoded to compensate for the channel induced intersymbol interference. The modulation apparatus has a symbol mapping circuit, which receives data symbols to be transmitted and maps the data symbols to a transmission code. The modulation apparatus compares two

adjacent data symbol digits, if the two adjacent data symbol digits have a first data level, the data symbol digits are transmitted. If the first digits of the data symbol digits has a first data level and a second digit of the data symbol digits has a second data level, the data symbols are also transmitted. However, if the first and second data symbol digits have a second data level, transmitting a first of the two adjacent data symbol digits is transmitted, a second of the two adjacent data symbol digits is converted to the first data level and the second data symbol digits is then transmitted.

[0026] The receiver has a demodulation apparatus to recover data symbols in the presence of the channel induced intersymbol interference. The demodulation apparatus has a sampling circuit in communication with a signal receiving circuit within the receiver to sample at a regular period received data symbols acquired by the receiving circuit. The samples of the data samples are retained by a sample retaining circuit in communication with the sampling circuit. The sample retaining circuit transfers the retained samples to a symbol mapping circuit. The symbol mapping circuit then recovers the data symbols.

[0027] The symbol mapping circuit executes a method for recovering the data symbols by first determining from two adjacent data symbol digits if a first state transition is present in the data symbol digits. The first state transition indicates that a first of the two adjacent data symbol digits is at the first data level and a second of the two adjacent data symbol digits is the second data level. If the first

state transition is present, a first state transition time is recorded. If the first state transition is not present the search to determine the first state transition continues until it is present.

[0028] When the first state transition is determined, a second state transition is  
5 determined to be present in the data symbol digits. The second state transition indicates that a first of the two adjacent data symbol digits is at the second data level and the first of the two adjacent data symbol digits is the second data level. When the second state transition is present, a second state transition time is recorded. The time difference between the first state transition time and the  
10 second state transition time is then calculated. If the time difference is less than a boundary time, at least one of any data symbol digits received subsequently to the second data symbol digit of the two adjacent symbol digits having the first state transitions is set to the first data level. If the time difference is greater than the boundary time, a first data symbol digit received subsequently to the second  
15 data symbol digit of the two adjacent symbol digits having the first state transition is set to the first data level and a second data symbol digit to the second data level.

[0029] All data symbol digits received subsequent to the second data symbol digit  
of the two adjacent symbol digits having the first state transition and prior to a  
20 data symbol boundary are set to the first data level. The data symbol digit arriving subsequent to the data symbol boundary to a second data level and all

remaining symbol digits of one data symbol subsequent to the data symbol boundary are set to the first data level.

[0030] The method for recovering the data symbols continues by determining if a last data symbol digit of a symbol is at the second data level. If the last data symbol digit is at the second data level, all symbol digits of a following data symbol are determined if they are at the first data level. If all the data symbol digits of the following data symbol are at the first data level, the first symbol digit of the following data symbol is set to the second data level.

### **Brief Description of the Drawings**

10 [0031] Fig. 1 is a diagram of the operation of a wireless radio transmitter and receiver illustrating channel induced interference of the prior art.

[0032] Fig. 2 is a timing diagram illustrating the effects of channel induced intersymbol interference on received digital data in wireless radio frequency channel of the prior art.

15 [0033] Fig. 3 is a diagram of the operation of a wireless infrared transmitter and receiver illustrating channel induced interference of the prior art.

[0034] Fig. 4 is a timing diagram illustrating the effects of channel induced intersymbol interference on received digital data in wireless infrared channel of the prior art.

[0035] Fig. 5 is a plot of a stream of pulse positioned modulated symbols being mapped to compensate for intersymbol interference of this invention.

[0036] Fig. 6 is a plot of a stream of pulse positioned modulated symbols transmitted and received demonstrating intersymbol interference of this invention.

[0037] Fig. 7 is a plot illustrating the detection of state transitions of a received stream of pulse positioned modulated symbols and from the state transitions of the received pulse positioned modulated symbols recovering the transmitted pulse positioned modulated symbols in the presence of intersymbol interference of this invention.

[0038] Fig. 8 is a plot illustrating the reconstruction of the pulse positioned modulated symbols from the received compensated symbol stream of this invention.

[0039] Fig. 9 is a block diagram of a transmitter of the communication system of this invention.

[0040] Fig. 10 is process flow diagram of the method for compensation of pulse positioned modulated signals of the transmitter of Fig. 9.

[0041] Fig. 11 is a block diagram of a receiver of the communication system of this invention.

[0042] Figs. 12a – 12c is process flow diagram of the method of for recovery of pulse positioned modulated signals of the receiver of Fig. 11.

### **Detailed Description of the Invention**

[0043] The intersymbol interference as described above limits the frequency

5 spectrum usable for the transfer of digital data. The transfer of long strings of zeros and ones or heavy toggling between zeros and ones causes corruption of the digital data due to the multipath effects that induce the intersymbol interference described. The use of pulse positioned modulation provides a relatively low switching rate. Once the receiving system is synchronized to the received signal, the recovery of the data is more reliable since the errors that occur are not position dependent and do not propagate. Certain symbol arrangements however, do cause limitation of the frequency due to the multipath effects that can create intersymbol interference. In symbol combinations (11) followed by (00), and (10) followed by a (00) of a four pulse position modulated encoded data, the intersymbol interference is sufficient to potentially corrupt the received data and make the transmitted data not recoverable. The method and system of this invention employs a recoding of the pulse positioned modulation to compensate for the symbol combinations (11) followed by a (00). The symbols combinations (10) followed by a (00) are determined as a result of the patterns detected.

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[0044] Refer now to Fig. 5 for a more detailed discussion of the recoding of the pulse positioned modulation to create a signal which then modulates the transmitted signal (either radio frequency or light signals). The PPM signal shows the digital data (0110001100010011) and formed partitioned to form the symbols **SYM 1**, ..., **SYM 8**. The symbols **SYM 2** and **SYM 3** contain the symbols 10 and 00 that are the first of the potential intersymbol interference candidates. The symbols **SYM 4** and **SYM 5** contain the symbols 11 and 00 that are the second of the potential intersymbol interference candidates.

[0045] In the case of the four pulse position modulation, as described in Fig. 4, each symbol is divided into four different times slots  $s_1$ ,  $s_2$ ,  $s_3$ , and  $s_4$ . Each time slot represents a digit of the symbol and only one of the four different times slots  $s_1$ ,  $s_2$ ,  $s_3$ , and  $s_4$  may contain the voltage level representative of the binary one. The intersymbol interference for the symbols **SYM 4** and **SYM 5** is compensated by placing the symbol digit  $s_1$  from a binary one for **SYM 5** to a binary zero for the transmission signal. This is an illegal character for the digital data and can be corrected at the receiver as describe hereinafter. Thus all symbols having a data pattern as shown for symbols **SYM 4** and **SYM 5** are recoded or mapped to the format of the transmit signal (**XMIT SIGNAL**), where the symbols **SYM 4** and **SYM 5** are now coded as (0001), (0000).

[0046] Referring to Fig. 6, the transmit signal (**XMIT SIGNAL**) modulates a wireless RF signal as described in Fig. 2 or a light signal as described in Fig. 4

for broadcast. The wireless RF or light signal is acquired at the receiver. The receiver amplifies wireless RF or light signal and recovers the received signal. The received signal is delayed as described in Figs 1 and 3 from the transmitted signal by a delay  $\delta$ . However, the reflected signals  $\lambda_2$  and  $\lambda_3$  of Figs. 1 and 3 delayed and are superpositioned on the direct signal  $\lambda_1$ .

[0047] The pulse width of each symbol digit of the pulse positioned modulated data is extended for at least a second symbol digit time slot  $s_1$ ,  $s_2$ ,  $s_3$ , or  $s_4$ . Thus the symbols **SYM 2** and **SYM 3** containing the symbols 10 and 00 are now merged to contain the symbol data (0011) (1100). If the reflected signals  $\lambda_2$  and  $\lambda_3$  of Figs. 1 and 3 are delayed even longer, the symbol data could actually be (0011) (1110). The symbols **SYM 4** and **SYM 5** are similarly corrupted to become (0001) (1000). Thus the recoded data of **SYM 5** is now interfered with from the previous symbol **SYM 4**.

[0048] The recovery of the received pulse positioned modulated signal is shown in Fig. 7. The rising transitions and the falling transitions of the received signal are recorded and the time difference  $\tau$  from the rising transition and the falling transition is determined. If the time difference  $\tau$  is less than a preset parameter, for instance the time of three symbol digits, the first symbol digit of the sequence of binary 1's is retained as the voltage level of the binary one and the remaining symbol digits are set to the voltage level of the binary zero. The symbols **SYM 4** and **SYM 5** illustrate this. The last symbol digit of symbol **SYM 4** and the first

symbol digit of the symbol **SYM 5** have a voltage level of a binary one. The last symbol digit of symbol **SYM 4** is retained at the voltage level of the binary one and the first symbol digit of the symbol **SYM 5** is set to the voltage level of the binary zero. This retains the recoding described above.

5 [0049] Alternately, if the time difference  $\tau$  is greater the preset parameter the first three symbol digits are set the voltage levels of the binary one, followed by the binary zero, followed by the binary one (101) and the remaining symbol digits of a symbol are set to the voltage level of the binary zero. The symbols **SYM 2** and **SYM 3** illustrate this recovery. The last two symbol digits  $s_3$  and  $s_4$  of the symbol **SYM 2** and the first two symbol digits  $s_1$  and  $s_2$  of the symbol **SYM 5** all have the voltage level of the binary one. The time from the rising transition between the second and third symbol digits of the symbol **SYM 2** and the falling transition between the third and fourth symbol digits of the symbol **SYM 3** is greater than the preset parameter (duration of 3 symbol digits). The third symbol digit  $s_3$  of the symbol **SYM 2** and the first symbol digit  $s_1$  of the symbol **SYM 3** are retained at the voltage level of the binary one and the last symbol digit  $s_4$  of the symbol **SYM 2** is set to the voltage level of the binary zero. The remaining symbol digits ( $s_3$  and  $s_4$ ) of the symbol **SYM 3** are set to the voltage level of the binary zero.

[0050] The recovered signal now reflects the transmitted signal of Figs. 5 and 6. Fig. 8 illustrates the final decoding to recover the received version of the original pulse positioned modulated data. The recovered data is examined for the

existence of a symbol code having a voltage level of a binary one at the fourth symbol digit  $s_4$  and all the symbol digits  $s_1$ ,  $s_2$ ,  $s_3$ , and  $s_4$  of the following symbol digit have a voltage level of a binary zero. The first symbol digit  $s_1$  of the following symbol digit is set to the voltage level of a binary one. Examining the symbols **SYM 4** and **SYM 5**, the last symbol digit  $s_4$  of the symbol **SYM 4** is at the voltage level of a binary one and the symbol digits  $s_1$ ,  $s_2$ ,  $s_3$ , and  $s_4$  of the symbol **SYM 5** are at the voltage level of the binary zero. The first symbol digit  $s_1$  of the symbol **SYM 5** is set to the voltage level of the binary one and the symbol codes for symbols **SYM 4** and **SYM 5** are recovered as (11) (00).

[0051] Refer now to Figs. 9 and 10 for a description of the structure and operation of the transmission subsystem of a communication system of this invention. Digital data  $D_0, \dots, D_n$  400 is acquired (Box 440) by the data input register 405. In this illustration the digital data is originally parallel data such as would be created, transformed, and stored in a computing system. The synchronizing clock circuit 410 provides the data clock 412 to gate the input digital data  $D_0, \dots, D_n$  400 to the data input register 405 at the data rate shown in Fig. 4. The data 407 retained by the data input register 405 is transferred to the pulse position modulator 415. The pulse positioned modulator 415 groups the data 407 to form (Box 445) multiple bit or binary digit symbols as shown in Fig. 4. For a four pulse positioned modulation, the data 407 is grouped into two bit or binary digital symbols. The synchronizing clock circuit 410 provides a pulse positioned clock 413 to the pulse positioned modulator 415 to determine the

pulse positioned modulation encoding (Box 450) for each of the formed symbols. The pulse positioned clock 413 is equivalent to the pulse positioned modulation clock 305 of Fig. 4. The pulse positioned modulation encoded symbols are then transmitted serially (Box 455) as the pulse positioned modulated data 417 to the pulse positioned modulation mapping circuit 420. The pulse positioned modulation mapping circuit 420 compares adjacent symbol digits of the pulse positioned modulation data 417 to map (Box 460) the pulse positioned modulation data 417 to provide a compensation for the presence of channel induced intersymbol interference. When two adjacent symbol digits are compared (Box 465) and are both at a voltage level of the binary one, the pulse positioned modulation mapping circuit sets (Box 470) the second symbol digit of the pair or symbol digits to the voltage level of the binary zero. The mapping of the pulse positioned modulated data 417 is equivalent to the method described in Fig. 5 where a data symbol (11) is adjacent to a data symbol (00). The pulse positioned modulation mapping circuit 420 has formed the transmission signal 422, which is transferred to the transmission signal modulation circuit 425. The transmission signal modulation circuit 425 modulates (Box 475) a signal 427 that is to be transmitted, either Frequency Shift Keying an RF Signal or gating a light signal. The modulated signal 427 is the input signal to the transmission driver that excites a transducer such as the transmission antenna 15 of Fig. 1 or the LED 210 of Fig. 3. The modulated signal 435 is then broadcast (Box 480) through the transmission medium.

[0052] An illustration of the structure and operation of the receiving subsystem of the communication system of this invention is shown in Figs. 11 and 12a – 12c. The modulated signal **500** is acquired (Box **555**) by a receiver **505** either through the antenna **20** of Fig. 1 or the LED **210** of Fig. 2. The amplifier and conditioning circuit **510** amplifies, demodulates, and conditions (Box **560**) the received signal **500** to create the received pulse positioned modulated data **512**. Generally, the transmitter of Fig. 9 will have embedded a synchronization signal and a start and/or stop signal within the transmitted signal. The synchronization signal is detected by the clock synchronization circuit **515** and the clock synchronization circuit **515** generates (Box **565**) a receiver system clock that is aligned to the embedded synchronization signal. The start signal indicates the beginning of the transmitted data follows immediately upon completion of the start signal. The stop signal indicates the completion of the data message and any following detected data signal is not part of the transmitted message. The start/stop recovery circuit detects the presence of the start and/or stop signals within the received pulse positioned modulated signal.

[0053] Upon detection (Box **570**) of the start signal, the received pulse positioned modulated data is sampled (Box **575**) by the data sampling circuit **525**. The clock synchronizing circuit **515** provides a sampling clock to provide at least one sample during a symbol digit  $s_1$ ,  $s_2$ ,  $s_3$ , and  $s_4$  time to determine the voltage level of the binary digit being sampled. The sampled pulse positioned modulated data **527** is transferred to the sample register **530** where is it retained (Box **580**) for

extraction of the transmitted pulse position modulated data that is corrupted by intersymbol interference. The retained samples are transferred to the sample mapping circuit **540**, which performs the extraction of the transmitted pulse positioned modulated data.

5    [0054]        The current sample for a symbol digit is compared (Box **585**) to a previous sample of a symbol digit. If the previous symbol digit is at the first voltage level indicating a binary zero and the current symbol digit is at the second voltage level indicating a binary one, a rising edge has occurred (Box **590**). If the rising edge has not occurred, but the comparison indicates that the previous symbol digit has  
10    the second voltage level indicating a binary one and the current symbol digit has the first voltage level indicating a binary zero, then a falling edge has occurred (Box **620**). However, if the previous and the current symbol digits are equal (either the first level indicating a binary zero or the second level indicating a binary one), then no transition has occurred and the next sample is taken (Box  
15    **575**) and retained (Box **580**) for comparison (Box **585**) with the now previous sample.

[0055]        When a rising edge occurs (Box **590**), the sample time at which the rising edge occurs is recorded (Box **595**). The difference time  $\Delta_1$  between the recorded time for the rising edge and a previous falling edge is determined (Box **600**).  
20    Upon comparison (Box **605**) with a preset time **P0** for instance  $3 \times \tau_s$  ( $\tau_s$  being the time duration of a symbol digit) if the difference time  $\Delta_1$  is not greater than the

preset time **P0**, the next sample is taken (Box 575) and retained (Box 580) for comparison (Box 585) with the now previous sample.

[0056] When a falling edge occurs (Box 620), The sample time at which the falling edge occurs is recorded (Box 625). The difference time  $\Delta_2$  between the logged time of the rising edge and the logged time of the falling edge is  
5 calculated (Box 630). The difference time  $\Delta_2$  is compared (Box 635) to a preset time **P1** (for instance  $3 \times \tau_s$ ). If the difference time  $\Delta_2$  is less than the preset time **P1**, the symbol digit at the rising edge having the voltage level of the binary one is retained (Box 640) at the binary one and all symbol digits remaining in the  
10 symbol up to the falling edge are set (Box 645) to the voltage level of the binary zero. This provides the recovery of the symbol digits as discussed above for **SYM 4** and **SYM 5** of Fig. 7.

[0057] If the difference time  $\Delta_2$  is greater than the preset time **P1**, the symbol digit (Slot 1) at the rising edge having the voltage level of the binary one is retained  
15 (Box 655) at the binary one. The adjacent symbol digit (Slot 2) is set (Box 660) to the voltage level of the binary zero and the next adjacent symbol digit (Slot 3) is retained (Box 665) at the voltage level of the binary one. This provides the recovery of the symbol digits as discussed above for **SYM 2** and **SYM 3** as discussed in Fig. 7.

[0058]        The difference time  $\Delta_2$  is then compared (Box 670) to an even longer preset time **P2** (for instance  $5 \times \tau_s$ ). If the difference time  $\Delta_2$  is greater the longer preset time **P2**, the final slot next to a symbol boundary is set (Box 675) to the voltage level of the binary zero. The first symbol digit (Slot 1) of the following symbol is retained (Box 680) at the voltage level of the binary one and all remaining slots of the symbol should be set (Box 685) to a binary zero. The sampling is skipped to the next symbol boundary (Box 690). The longer preset time **P2** allows for the recovery of a set of symbol digits having a coding of (101001) from a received corrupted pulse position modulated data of (11111111). The worst incidence of this occurring would permit the reception of the received pulse position modulated data (0001) (1111) (1110) and then recovery of the transmitted (0001) (0100) (1000).

[0059]        Upon completion of the recovery of the transmitted pulse positioned modulated data, the next sample is taken (Box 575) and retained (Box 580) for comparison (Box 585) with the now previous sample. If a rising edge is determined (Box 590), the time of the rising edge is recorded (Box 595). The difference time  $\Delta_1$  between the previous falling edge and the present rising edge is determined (Box 600). The difference time  $\Delta_1$  is compared (Box 605) to the preset time  $3 \times \tau_s$  and if the difference time  $\Delta_1$  is greater than the preset time  $3 \times \tau_s$ , the first symbol digit (Slot 1) of the symbol subsequent to the falling edge is set (Box 610) to the voltage level of the binary one. The remaining symbol digits

are retained at the voltage level of the binary zero and the sampling skips (Box 615) to the next symbol boundary. The sampling and recovery process then continues until the message is complete with the reception of a stop signal or synchronization signal.

5 [0060] Returning to Fig. 11, the pulse position modulated data 540 recovered by the symbol mapping circuit 535 is transferred to the data extraction circuit 545. The data extraction circuit 545 decodes the pulse position modulated data to extract the data symbols and assemble the data symbols to the originally encoded data.

10 [0061] The symbol mapping circuit 535 and the data extraction circuit 545 are in the preferred embodiment logical state machines capable of extremely high speed recovery of the data symbols and extraction of the data. However, it is known in the art that the structure and method described above may be accomplished within a digital signal processor or similar computing system with  
15 the functions and processes being programs stored on data storage medium for execution by the processes.

[0062] Further, the preferred embodiment illustrates a four pulse positioned modulated data signal. It is in keeping with the intent of this invention that any number of pulse position modulated symbol digits may be employed to encode  
20 the digital data. The structure and method of the communications system of this invention functions with a higher order pulse position modulated encoding.

[0063] The communications systems as shown in Figs. 1 and 3 illustrate wireless transmission of the broadcast modulated signal. It is keeping with the intention of this invention that the modulated signal be transmitted within a cable, either an electrical signal in a copper cabling or a light signal within a fiber optic cable.

5 [0064] While this invention has been particularly shown and described with reference to the preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made without departing from the spirit and scope of the invention.

[0065]

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## CLAIMS

1. A communication system for the transmission and recovery of data symbols the presence of channel induced intersymbol interference, said communication system comprising:
  - a transmitter for transmitting a signal containing said data symbols comprising:
    - a modulation apparatus connected to receive data and convert said data to data symbols, said data symbols encoded to compensate for the channel induced intersymbol interference, said modulation apparatus comprising:
      - a symbol mapping circuit which receives data symbols to be transmitted and maps said data symbols to a transmission code by the steps of:
        - a) comparing two adjacent data symbol digits,
        - b) if said two adjacent data symbol digits have a first data level, transmitting said data symbol digits,
        - c) if said data symbol digits have the first data level and a second data level, transmitting said data symbols, and

d) if said data symbol digits have the second data level, transmitting a first of said two adjacent data symbol digits, converting a second of said two adjacent data symbol digits to the first data level and transmitting said second data symbol digits; and

a receiver for acquiring said signal containing said data symbols, recovering said data symbols, and extracting said data, said receiver comprising:

a demodulation apparatus within a receiving system to recover data symbols is the presence of channel induced intersymbol interference comprising:

a sampling circuit in communication with a receiving circuit within said receiving system to sample at a regular period received data symbols acquired by said receiving circuit,

a sample retaining circuit in communication with the sampling circuit to store samples of the data symbols, and

a symbol mapping circuit in communication with the sample retaining circuit for receiving said samples of

the data symbols and for executing a method for recovering said data symbols, said method for recovering said data symbols comprising the steps of:

a) determining from two adjacent data symbol digits if a first state transition is present in said data symbol digits, said first state transition indicating that a first of the two adjacent data symbol digits is at the first data level and a second of the two adjacent data symbol digits is the second data level,

b) if the first state transition is present, recording a first state transition time,

c) if the first state transition is not present repeating step a) until said first state transition is present,

d) when said first state transition is determined, determining if a second state transition is present in said data symbol digits, said second state transition indicating that a first of the two adjacent data symbol digits is at the second

62 data level and the first of the two adjacent data  
63 symbol digits is the second data level,

64 e) if the second state transition is present,  
65 recording a second state transition time,

66 f) determining a time difference between the first  
67 state transition time and the second state  
68 transition time,

69 g) if the time difference is less than a boundary  
70 time, setting at least one of any data symbol  
71 digits received subsequently to the second  
72 data symbol digit of the two adjacent symbol  
73 digits having the first state transitions to the  
74 first data level, and

75 h) if the time difference is greater than the  
76 boundary time, setting a first data symbol digit  
77 received subsequently to the second data  
78 symbol digit of the two adjacent symbol digits  
79 having the first state transition to the first data  
80 level and a second data symbol digit to the  
81 second data level.

1     2.     The communication system of claim 1 wherein the method for recovering  
2            said data symbols further comprises the steps of:

3            setting all data symbol digits received after the second data symbol  
4            digits subsequent to the second data symbol digit of the two  
5            adjacent symbol digits having the first state transition and prior  
6            to a data symbol boundary to the first data level; and

7            setting a data symbol digit arriving subsequent to said data symbol  
8            boundary to the second data level and all remaining symbol  
9            digits of one data symbol subsequent to said data symbol  
10          boundary to the first data level.

1     3.     The communication system of claim 1 wherein the method for recovering  
2            said data symbols further comprises the steps of.

3            determining if a last data symbol digit of a symbol is at the second  
4            data level;

5            if said last data symbol digit is at the second data level, determining  
6            if all symbol digits of a following data symbol are at the first data  
7            level; and

8            if all the data symbol digits of the following data symbol are at the  
9            first data level, setting the first symbol digit of the following data  
10          symbol to the second data level..

1 4. A modulation apparatus within a transmission system to compensate for  
2 channel induced intersymbol interference causing corruption of data  
3 symbols during broadcast of said data symbols from said transmission  
4 system, said modulation apparatus comprising:

5 a symbol mapping circuit which receives data symbols to be  
6 transmitted and maps said data symbols to a transmission code  
7 by the steps of:

8 a) comparing two adjacent data symbol digits,

9 b) if said two adjacent data symbol digits have a first data  
10 level, transmitting said data symbol digits,

11 c) if said data symbol digits have the first data level and a  
12 second data level, transmitting said data symbols, and

13 d) if said data symbol digits have the second data level,  
14 transmitting a first of said two adjacent data symbol digits,  
15 converting a second of said two adjacent data symbol  
16 digits to the first data level and transmitting said second  
17 data symbol digits.

1 5. A demodulation apparatus within a receiving system to recover data  
2 symbols is the presence of channel induced intersymbol interference  
3 comprising:

4 a sampling circuit in communication with a receiving circuit within  
5 said receiving system to sample at a regular period received  
6 data symbols acquired by said receiving circuit;

7 a sample retaining circuit in communication with the sampling  
8 circuit to store samples of the data symbols; and

9 a symbol mapping circuit in communication with the sample  
10 retaining circuit for receiving said samples of the data symbols  
11 and for executing a method for recovering said data symbols,  
12 said method for recovering said data symbols comprising the  
13 steps of:

14 a) determining from two adjacent data symbol digits if a first  
15 state transition is present in said data symbols, said first  
16 state transition indicating that a first of the two adjacent  
17 data symbol digits is at the first data level and a second of  
18 the two adjacent data symbol digits is the second data  
19 level,

20 b) if the first state transition is present, recording a first state  
21 transition time,

22 c) if the first state transition is not present repeating step a)  
23 until said first state transition is present,

24 d) when said first state transition is determined, determining  
25 is a second state transition is present in said data  
26 symbols, said second state transition indicating that a first  
27 of the two adjacent data symbol digits is at the second  
28 data level and the first of the two adjacent data symbol  
29 digits is the second data level,

30 e) if the second state transition is present, recording a  
31 second state transition time,

32 f) determining a time difference between the first state  
33 transition time and the second state transition time,

34 g) if the time difference is less than a boundary time, setting  
35 at least one of any data symbol digits received  
36 subsequently to the second data symbol digit of the two  
37 adjacent symbol digits having the first state transitions to  
38 the first data level, and

39 h) if the time difference is greater than the boundary time,  
40 setting a first data symbol digit received subsequently to  
41 the second data symbol digit of the two adjacent symbol  
42 digits having the first state transition to the first data level  
43 and a second data symbol digit to the second data level.

1 6. The demodulation apparatus of claim 5 wherein the method for recovering  
2 said data symbols further comprises the steps of:

3 setting all data symbol digits received after the second data symbol  
4 digits subsequent to the second data symbol digit of the two  
5 adjacent symbol digits having the first state transition and prior  
6 to a data symbol boundary to the first data level; and

7 setting a data symbol digit arriving subsequent to said data symbol  
8 boundary to the second data level and all remaining symbol  
9 digits of one data symbol subsequent to said data symbol  
10 boundary to the first data level.

1 7. The demodulation apparatus of claim 5 wherein the method for recovering  
2 said data symbols further comprises the steps of.

3 determining if a last data symbol digit of a symbol is at the second  
4 data level;

5 if said last data symbol digit is at the second data level, determining  
6 if all symbol digits of a following data symbol are at the first data  
7 level; and

8 if all the data symbol digits of the following data symbol are at the  
9 first data level, setting the first symbol digit of the following data  
10 symbol to the second data level.