IPC

Industrial Powerline Communications

Technical Overview

February 2012
OVERVIEW

Industrial Powerline Communications (IPC) is the powerline communication technology designed by Powerline Control Systems for the three-phase commercial/industrial environment. PCS has been the leader in powerline communication for over 15 years.

HISTORY

In 1997, PCS began developing a new communication technology that utilizes the existing electrical power wires (the powerline) as its main transmission medium. Our first offering, the Universal Powerline Bus (UPB) communication technology, utilized an innovative and patented Pulse Position Modulation (PPM) method to transmit digital information onto the powerline. The physical layer method employed by UPB was very different than the usual modulated/demodulated RF techniques used by many other powerline-based technologies at the time such as X-10, Intellon, Echelon, Itron, Inari, and LiteTouch.

X-10 and SceneMaster (1996 – 2006)

In 1996, based on the X10 communication technology and the X10 message structure and protocol, PCS successfully introduced a full line of residential lighting control products under the trade name of SceneMaster™. PCS was the first company to introduce a communicating Decora dimmer switch. This revolutionary “smart” switch was branded the SceneMaster™ SmartSwitch™. Soon PCS produced an entire line SceneMaster based products such as wall controllers and load control modules. These products were all made in the US and much more reliable than similar X-10 based products. Although reliable and incorporating a built in scene control system the SceneMaster product line was limited by the reliability issues inherent in the X-10 powerline technology and the very limited capabilities of the X-10 message protocol. Currently there are several 1000’s of SceneMaster installations in the US, Canada, and Mexico. The UPB based PulseWorx product line eventually replaced all sales of the SceneMaster product line.

UPB and PulseWorx (2003 – present)

Based on its UPB™ technology, PCS successfully introduced a full line of residential lighting control products under the trade name of PulseWorx™. These products are approximately 10 times more reliable than similar X-10 based products and can be installed without the use of filters, or repeaters. Universal Powerline Bus has been considered a success in the residential lighting control industry. PCS continues to license the UPB™ technology into all appropriate residential and light commercial markets and applications. Currently there are several 1000’s of UPB installations in the US, Canada, and Mexico. There are a variety of 230V 50HZ locations scattered the world over.
IPC and GreenWorx (2004 – present)

In 2004, PCS began focusing on developing a new, more robust, powerline communication technology specifically designed for the high-noise, high-attenuation three phase commercial/industrial environment. This new variation of the pulse-position-modulation technology, named Industrial Powerline Communications (IPC), is derived from the basic UPB method but incorporates many advancements, as outlined in Table 1, that make it ideally suited for the commercial/industrial environment.

PCS is specifically targeting IPC for the commercial/industrial high-bay and parking structure markets. GreenWorx can control florescent, induction and LED fixtures all of which are used in both the high-bay and parking structure markets. As more IPC™ products are introduced by PCS there will be an increased number of product offerings varying in price and sophistication. Because of the low cost of the two-way transmission-receiving components, IPC™ products will be introduced into a wide variety of high-volume, low-cost Industrial/Commercial lighting controls.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>UPB™</th>
<th>IPC POWERED</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Brand Name</td>
<td>PulseWorx</td>
<td>GreenWorx</td>
</tr>
<tr>
<td>Fastest Command Transmission</td>
<td>.3 sec</td>
<td>1.2 sec</td>
</tr>
<tr>
<td>Pulses per full 60Hz Cycle</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Bits per full 60Hz Cycle</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Reliability</td>
<td>High</td>
<td>Extremely High</td>
</tr>
<tr>
<td>Noise Resistance</td>
<td>High</td>
<td>Extremely High</td>
</tr>
<tr>
<td>Requires Repeater</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Max Circuit Breaker Panels</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Max Voltage</td>
<td>220VAC</td>
<td>480VAC</td>
</tr>
<tr>
<td>Three Phase</td>
<td>Available as add-on</td>
<td>Yes</td>
</tr>
<tr>
<td>Setup Program</td>
<td>UPStart</td>
<td>GreenWorx</td>
</tr>
<tr>
<td>Maximum # Devices</td>
<td>250</td>
<td>3,750</td>
</tr>
<tr>
<td>Remote Firmware Update</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 1: UPB and IPC Parameters
**Patent Protection**

PCS has been and continues to be diligent in protecting its pulse-position-modulation communication technology. As the UPB and IPC communication methods are improved patents will be obtained covering all important aspects of the technology. To date, PCS has been issued five patents on the pulse-position powerline communication technology and will continue to develop a significant portfolio of patents and other Intellectual Property as our technologies evolve. Both UPB™ and IPC™ products are covered by all the PCS patents.

<table>
<thead>
<tr>
<th>No.</th>
<th>Patent/Application Number</th>
<th>Filing Date Issue date</th>
<th>Expires</th>
<th>Country/Jurisdiction</th>
<th>Title/Description</th>
<th>Status</th>
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<tr>
<td>2</td>
<td>6,784,790</td>
<td>6/14/2000 8/31/2004</td>
<td>6/14/2020</td>
<td>United States</td>
<td>SYNCHRONIZATION/REFERENCE PULSE-BASED POWERLINE PULSE POSITION MODULATED COMMUNICATION SYSTEM</td>
<td>Issued, In Force</td>
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<td>5</td>
<td>11/431,161</td>
<td>5/9/2006</td>
<td></td>
<td>United States</td>
<td>APPLICATION FOR REISSUE OF ZERO CROSSING BASED POWERLINE PULSE POSITION MODULATED COMMUNICATION SYSTEM PATENT</td>
<td>Pending</td>
</tr>
<tr>
<td>7</td>
<td>8,294,556</td>
<td>03/25/2008 10/23/2012</td>
<td>10/23/2032</td>
<td>United States</td>
<td>ZERO CROSSING BASED POWERLINE PULSE POSITION MODULATED COMMUNICATION SYSTEM (IPC TECHNOLOGY)</td>
<td>Issued, In Force</td>
</tr>
<tr>
<td>8</td>
<td>61,538,871</td>
<td>25/09/2011</td>
<td></td>
<td>United States</td>
<td>POWERLINE PULSE POSITION MODULATED THREE PHASE TRANSMITTER APPARATUS AND METHOD (IPC TECHNOLOGY)</td>
<td>Pending</td>
</tr>
</tbody>
</table>
HOW UPB and IPC WORK

The fundamentals of UPB™ or IPC™ communication are really quite simple. A series of short pulses are generated onto the AC sine wave in synchronization with the main line voltage frequency. For IPC one pulse is generated per negative half-cycle of the powerline and for UPB one pulse is generated per negative and positive half-cycles of the powerline. The relative position of each pulse may vary over a small range of time or “position” relative to the previous pulses. Because the digital data is encoded into these differences in position, the method of modulation is called Pulse Position Modulation or PPM.

Figure 1: UPB Pulses

The function of an UPB™ or IPC™ transmitter is to produce the series of precisely time pulses that encode a digital message to be transmitted. The function of the IPC™ receiver is to detect the pulses, determine their “positions”, separate the pulses from noise, and finally reproduce the digital message.

A typical series of UPB™ pulses is shown in Figure 1, which is taken directly from an oscilloscope output using the PulseWorx receiving circuit. IPC Pulses are similar but only one pulse is generated per full AC cycle instead of two.

A very simple circuit that discharges a small capacitor onto the powerline produces the IPC™ pulse. The pulse that is produced is very similar to a pulse produced by a lamp dimmer every half cycle that the lamp is turned on. The IPC™ transmitter produces a small number of pulses only when a communication packet is being transmitted. This is far less disruptive than a conventional lamp dimmer which produces one pulse every half cycle as long as the lamp is on.

A simple way of summarizing our method of powerline communication is:
“The IPC physical method of communication utilizes the equivalent of triac-based dimmer noise pulses in combination with a PPM technique to transmit digital information over the powerline.”

A typical UPB™ or IPC™ pulse with the power sine wave filtered out is shown in Figure 2 below.

**IPC RELIABILITY**

In order to communicate successfully on an industrial building’s powerline you must start with an extremely reliable physical layer communication method. The transmitted data must travel over hundreds or thousands of feet of electrical wiring, affected by multiple attenuation and noise sources, and finally arrive at the intended receiver with enough of its original content to be detected and decoded. Fortunately, the IPC physical layer (the “pulse”) has four fundamental parameters that taken together make it perfect for industrial/commercial powerline communication.

**Instantaneous Transmission Power**

The first parameter that helps make the IPC pulse travel so well is the fact that its energy per unit time is several hundred times greater than the steady state energy of any of the modulated/demodulated RF techniques (Figure 3). This short burst of strong energy tends to travel great distances and is easily detected even after significant attenuation.
An analogy that illustrates this concept is the sounds produced by the two musical instruments, cymbals and a violin. The energy produced as cymbals are struck together is much different than that of a violin producing a note. The sound produced by the cymbals is very short but loud and is produced by quickly releasing the stored kinetic energy as the two cymbals are brought together. The violin sound is produced over a relatively long period of time by continually outputting more energy. The violin might release more energy over one second but the peak energy is only a small fraction of the peak energy released as the cymbals collide. It is much easier to detect, or hear, a cymbal crash than a violin note at a great distance.

**Low Frequency Content**

The second parameter that enables the IPC pulse to proliferate so well is its low frequency content. The natural distribution of attenuation in a home or building decreases as the frequency decreases. This means that, lower frequencies get around the building power wiring, and especially get across the phases of the utility supply transformer, much better than higher frequencies (see Figure 4 below).
The energy content of the IPC™ pulses vary over a frequency range of approximately 4 KHz to 40 KHz, which is much lower than the frequencies utilized by the other powerline communication technologies. The other powerline technologies use frequencies in the range of 80kHz ~ 400kHz or in the MHz range. An analogy that shows this effect clearly is the sound heard coming from another car with the windows of both cars rolled up. We have all noticed that you can hear the lowest base boom-boom sounds clearly even when the higher frequency sounds are completely blocked (attenuated). The lower frequencies contain so much more energy than the higher frequencies that they are very difficult to attenuate. This works to the advantage of both UPB and IPC.

**Wide Frequency Band**

The third parameter that helps make the IPC pulse travel so well is the fact that the frequency content of the pulses varies over such a wide range. The frequency range that makes up a UPB or IPC pulse is approximately 4 KHz to 40 KHz (Figure 5).

Because this is a relatively wide range of frequency content, which covers one complete decade of frequency variation, the IPC pulse proliferates like a spread spectrum, broadband-type signal. If some parts of the 4 KHz to 40 KHz are heavily attenuated, enough of the bandwidth is left un-attenuated so that the IPC™ pulse can still be easily detected. This “wide-band” transmission, is the basic method used in spread spectrum technologies to overcome narrow-band attenuation effects. This is the third great advantage of the PCS pulse-position method.
**Direct Circuit Transmissions**

The forth parameter that helps make the IPC pulse travel so well is the fact that the communication packets sent to IPC control modules, typically installed in lighting fixtures, are transmitted directly into the circuit breaker panel to which the fixtures are wired. The architecture of the IPC system (shown on the following page) shows that there is a three-phase system transmitter/receiver installed on every circuit breaker panel to which fixtures to be controlled are wired. The system allows for one central control unit, labeled the GreenWorx System Controller (GSC) to communicate over the powerline by means of up to eight GreenWorx System Extenders (GSX), which handle all the direct two-way communication into and from the high-voltage powerlines.

This architecture is very simple yet very powerful. The ability to transmit directly into and to receive from each circuit breaker panel achieves the highest possible reliability.

**Automatic Gain Control (AGC)**

Every GreenWorx module has built-in AGC. The GreenWorx system in NOT a peer-to-peer system like UPB systems. Any specific fixture module (FCM) always receives messages from the same GSX unit. Since the signal strength at the receiver does not change the receiver can use the measured signal strength to set it’s own internal receive sensitivity. This allows every FCM to optimize the receive sensitivity to minimize the effects from any noise or attenuation present. The AGC is constantly adjusted up or down (or remaining the same) every time a message is received. If the building power is ever cycled the AGC level returns to the most sensitive and begins adjusting again.
The GreenWorx Lighting Control System

3-Phase Powerline

Circuit Breaker Panel

8 Circuit Breaker Panels Maximum

3-Phase Powerline

Circuit Breaker Panel

4-conductor twisted-pair
RS-485
Max 4000'

GNC

8 RNIs Maximum

GNC

8 RNIs Maximum

GNC

RS-232

Computer
(Setup or EMS)

GNC

ZLC

RS-232

GWX

Software

One or more Zone Lighting Controllers connected to any single phase of the powerline

Each ZLC has 8 optional dry-contact switch closure sensing inputs

GNC

Circuit Breaker Panel

Circuit Breaker Panel

Circuit Breaker Panel

Circuit Breaker Panel

Lighting Controls

Fixture Control Modules
(attached to Lighting Fixtures)
**THE IPC PROTOCOL**

The IPC™ message structure is a very simple straightforward format supporting message data packets from 0-18 bytes. The two-way protocol allows for message acknowledgement and the ability to download and store all relevant information from all IPC™ devices.

**The IPC Communication Packet**

The digital 0’s and 1’s on the powerline are strung together in consecutive cycles of the powerline to communicate useful information (messages) from one device to other devices. IPC defines a variable length (from 8 to 25 byte) structure called an IPC Communication Packet (Figure 6) in order to give those bits meaning. The IPC Communication Packet forms the basis of all IPC powerline communication.

<table>
<thead>
<tr>
<th>Field</th>
<th>Bits</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTRL</td>
<td>2 bytes</td>
<td>The first 16-bits of the IPC Communication Packet are defined as its Control Field. The Control Field contains various bits and fields that define the type and length of the packet as well as to request special ways for the receiver to respond to the packet.</td>
</tr>
<tr>
<td>NID</td>
<td>1 byte</td>
<td>The Network Field indicates the Network ID of the device(s) that the packet is intended for. IPC devices are assigned an 8-bit Network ID between 1 and 255. They will reject IPC Communication Packets that don’t match their own Network ID. This is intended as a mechanism to separate two or more networks of IPC devices that share the same power transformer.</td>
</tr>
<tr>
<td>DID</td>
<td>1.5 bytes</td>
<td>The Destination Field indicates the intended destination of the packet. Each IPC device is assigned a unique 12-bit Device ID so that it can be uniquely distinguished from all other devices. In addition, most IPC devices can be assigned numerous (usually 16) 12-bit Group IDs that are not unique. Group IDs can be shared with other devices to form groups or scenes. The Destination Field indicates the Device ID (or Group ID) of the device(s) that the packet is directed to.</td>
</tr>
<tr>
<td>SID</td>
<td>1.5 bytes</td>
<td>The Source ID indicates the source of the packet. It can be used to verify the origin of the message or to identify the device that originated the message.</td>
</tr>
<tr>
<td>MSG</td>
<td>1 – 18 bytes</td>
<td>The message data packet contains the actual information being transmitted. It can range from 1 to 18 bytes in length.</td>
</tr>
<tr>
<td>CHK</td>
<td>1 byte</td>
<td>The checksum is a 1-byte value that is calculated based on the message data packet. It is used to verify the integrity of the packet and ensure that the message has not been corrupted during transmission.</td>
</tr>
</tbody>
</table>

**Figure 6: IPC Communication Packet**

The bits and fields that make up the IPC Communication Packet are described below.

**The Control Field (CTRL)**

The first 16-bits of the IPC Communication Packet are defined as its Control Field. The Control Field contains various bits and fields that define the type and length of the packet as well as to request special ways for the receiver to respond to the packet.

**The Network Field (NID)**

The next byte of the IPC Communication Packet is defined as the Network Field. The Network Field indicates the Network ID of the device(s) that the packet is intended for. IPC devices are assigned an 8-bit Network ID between 1 and 255. They will reject IPC Communication Packets that don’t match their own Network ID. This is intended as a mechanism to separate two or more networks of IPC devices that share the same power transformer.

**Destination Field (DID)**

The next 12-bits of the IPC Communication Packet are defined as the Destination Field. The Destination Field indicates the intended destination of the packet. Each IPC device is assigned a unique 12-bit Device ID so that it can be uniquely distinguished from all other devices. In addition, most IPC devices can be assigned numerous (usually 16) 12-bit Group IDs that are not unique. Group IDs can be shared with other devices to form groups or scenes. The Destination Field indicates the Device ID (or Group ID) of the device(s) that the packet is directed to.
intended for. The GRP bit (in the Control Field) indicates if the value in the Destination Field is a Device ID (GRP = 0) or a Group ID (GRP = 1).

**Source Field (SID)**
The next 12-bits of the IPC Communication Packet are defined as the Source Field. The Source Field indicates the Device ID of the device that generated the packet. This information will allow receivers of a packet to generate response packets addressed specifically to the requester.

**Message Field (MSG)**
The next field of the IPC Communication Packet is defined as the Message Field. The Message Field is a variable length (from 1 to 18 byte) field that identifies the useful information (command or report) of the packet.

**Checksum Field (CHK)**
The last byte of the IPC Communication Packet is the Checksum Field. The 8-bit value in this field is used by the receivers to verify the data integrity of the received packet. The checksum value is calculated such that the 8-bit sum of all of the packet bytes (including the Checksum Field) results in 0.

**Communication Packet Synchronization**
All IPC Communication Packets are immediately preceded by four Sync Pulses transmitted as digital bits 1-0-0-1. The purpose of the Sync Pulses is to allow receivers to identify the start of a packet and synchronize their timing with it.

**IPC DEVICE REGISTERS**
All IPC™ devices contain a set of non-volatile memory registers to store identification and configuration information (refer to Table 2). Each IPC™ device is assigned a Network ID (NID) that can range from 001 to 250. By assigning the same Network ID to a group of IPC™ devices, a virtual network can be formed by those devices. Each IPC™ device is also assigned a unique Device ID that can range from 1 to 3750. The Device ID (DID) is used to distinguish each individual device from all other devices on the same IPC™ network.

Each IPC device has three text fields for use by the installer to store replacement information such as Panel# and Circuit#. This information along with other configuration fields allows the installer to download and save all relevant configuration information. This will greatly simplify future modifications and troubleshooting. Using appropriate higher-level interface software, installers will be able to remotely analyze or modify IPC devices.
### Table 2: IPC Setup Registers

The configuration registers are different for different types of devices. These registers contain links, scenes and various other information that determines how any one device behaves.

**SUMMARY**

One of the primary reasons powerline communication-based and wireless-based lighting systems have not captured a significant portion of the massive Industrial/Commercial controls market has been the lack of reliable cost-effective communications. The IPC™ technology promises to supply the “last leg” of Internet to fixture connectivity that has eluded the communication industry thus far. Without a highly-reliable yet low-cost low-bandwidth solution to the Industrial/Commercial communication problem, total connectivity will never be possible. IPC™ allows that functionality to become a reality.