A Low-Cost Power-Line Node for Domestic Applications

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Abstract

Power-line is a very attractive communication media for domestic applications. It allows a very easy installation of a comprehensive network without any additional wiring. Consequently, the installation costs will be reduced, which is a key requirement for the consumer market.

This paper describes ATICON’s low-cost solution of an innovative node for domestic applications, which integrates the power supply, power-line modem, line interface, application processor and an opto-galvanically separated i/o interface on a small printed circuit board of 61 x 113 mm.

1 Introduction

The continuing progress in microelectronic technology leads to a plentitude of discrete and distributed microsystems in a modern household. New applications like home automation become possible: similar to networked computers, the efficiency and functionality of domestic appliances can be increased considerable, if they have the ability to exchange informations. In other words, home automation is the process of linking domestic appliances to a global network.

A practical example is energy management, reduction of peak power consumption of white goods (washing machines, refrigerators, dish washers etc.). Each of these devices does not need its power continuously, but only for a certain period (e.g., washing machines need their power mostly in heating intervals, and the refrigerator only when the coolant pump works). If these periods can be interlaced, peak power consumption will be reduced and energy becomes cheaper. Other possible scopes of home automation are security (burglar alarm systems), safety (water leak detectors etc.), increase of comfort (e.g. remote control), entertainment (audio/video etc.) or HVAC (Heating, Ventilation and Air Conditioning) [2].

Home automation has its own demands on the communication technology. Because the consumer market is very cost sensitive, an easy installation procedure of the whole home automation network has to be supported. This includes the use of existing structures for data transmission to allow the retrofitting of home automation applications.

Power-line communication technology fulfills these requirements by using the existing electrical wiring found in any house.

CENELEC, the European Committee for Electrotechnical Standardization, defined the transmission on low-voltage installations in the EN50065-1 document. The standard is mandatory for all country members of the CENELEC organization and has been published in germany by the German Commission for DIN and VDE as DIN-EN 50065-1, classification VDE 0808 [3]. It has to be complied by power-line products for home automation purposes and defines four different frequency bands:

- frequencies from 3 kHz to 95 kHz which are reserved for energy suppliers (A-band),
- frequencies from 95kHz to 125 kHz which may be used by any application (B-band) without using an access protocol;
- frequencies from 125 kHz to 140 kHz which are reserved to home automation products (C-band). A mandatory CSMA (Carrier Sense Multiple Access) algorithm allows the co-existence of different systems in this frequency band; and finally
- frequencies from 140 kHz to 148.5 kHz (D-band), which may be used by alarm and security systems without an access protocol.

2 EHS - a Common European Standard

To increase attractivity and acceptance of home automation technology for the final user, compatibility between all appliances must be achieved. Several EUREKA- and ESPRIT-projects have been launched by the European Community to support the development of a common European standard for home automation [4]. Notable European companies were involved in these projects, like ABB, AEG/Daimler-Benz, British Telecom, Electricité de France (EdF), Electrolux, GEC, Philips or Siemens. The result is the European Home System Network (EHS), a comprehensive home communication system [5], [6]. EHS defines six different physical medium for exchanging information between domestic appliances: power-line, twisted pair (9.6 kBaud), twisted pair 2 (64 kBaud, ISDN), coaxial, infrared, and radio frequency.
A smart plug & play mechanism completes the very easy installation concept of power-line technology. This includes the automatic assignment of network addresses (registration) and application links (enrolment). Hence, the whole network can be installed by the customer without help from a professional (and expensive) installer. The standarized and well-defined command language of EHS gives the applications their flexibility and is a fundamental prerequisite to a plentitude of new products from different manufactures. Therefore, the combination of power-line communication and EHS protocol offers low-cost solutions to home automation systems.

3 EHS Power-Line Medium

Power-line communication is a standarized medium of the EHS specification. It defines a 2400 half duplex protocol with MFSK (Minimum Frequency Shift Keying) modulation. The EHS power-line medium complies to the CENELEC EN 50065-1 standard and uses the C-band with a CSMA (Carrier Sense Multiple Access) collision avoidance. The centre frequency is 132.5 kHz, the frequency deviation for data transmission ±0.6 kHz. A logical '1' is represented by the lower frequency (131.9 kHz) and a logical '0' by the upper frequency (133.1 kHz). As defined in CENELEC, the output level of a power-line transmitter using the C-band shall not exceed 116 dB(µV).

The main difference to common serial data protocols is the absence of a start or stop bits surrounding every data byte. Instead a leading 16-bit preamble containing 8 falling and 8 rising edges will be used to synchronize receiver and transmitter. A following 16-bit header code allows the recognition of EHS-datagrams or EHS-acknowledges even if some bits have been destroyed due to noise on the power-line network.

Each byte of the following sequence is extended by a 6 bit Forward Error Correction (FEC), hence every 8 data bits are transmitted by a field of 14 bits. The generator polynomial of the FEC \((x^8+x^4+x^3+1)\) is capable to correct up to three succeeding bit-errors within 14 bits. This mechanism is well-suited to compensate disturbances caused by switch mode power supplies or light dimmers, which can generate during approximately 1 ms a pulse noise occurring mostly every same phase angle.

It has already been mentioned that an EHS power-line packet can either be a datagram or an acknowledge. The purpose of datagrams is the transmission of control informations (e.g. 'light on'). Acknowledges confirm the reception of a datagram by the receiver. First, datagrams shall be described.

An EHS power-line datagram begins with a 16 bit house address, which allows the coexistence of several EHS-compliant home automation systems in the same power-line network. A following link control field contains the 4-bit modulo 16 transmission number and ensures that retransmitted commands will not be executed twice. Because priority mechanisms are difficult to realize in power-line technology, the priority code will not be used to give some packets a higher priority than others; ist main purpose is to separate group addresses from individual addresses.

Furthermore, EHS power-line datagram contains an 8 bit source address and an 8 bit destination address, both are sub-network addresses within the power-line network. The following data area is up to 68 bytes long and leaded by a length byte. The maximum frame length of packets transferred in the CENELEC C-band depends on the maximum transmission time specified by the CSMA access protocol. The data area itself is a tuple of EHS commands defined in the EHS command language using the syntax \(object, service, data\)

The last field of an EHS power-line datagram is a 16 bit Frame Check Sequence (FCS), which ensures the consistency of the whole packet. If a datagram has been transmitted correctly, only the FCS field is returned to the sender as an acknowledge.

4 Hardware

The low-cost power-line node combines a power-line modem, power-line interface, power supply, application processor and an opto-galvanically separated i/o-interface on a small pcb. It has been designed in Surface Mounted Technology (SMT)and uses standard components for cost reduction. Of course, further integration can be achieved by ASIC design in future.

Figure 2 shows the block diagram of the control unit's hardware. Each part of the power-line node will now be described in sub-chapters.

4.1 Power-Line Modem

The modem of the low-cost node has been realized with the EHS-compliant ST7537 power-line modem from SGS Thomson [7]. It generates the MFSK-modulated signals, supervises the CSMA collision avoidance protocol and provides clock, reset and watchdog to the system. The communication interface to the microcontroller is simple.
and consists of 4 pins: $Tx$ for transmitting signals, $Rx_Tx$ to shift between transmit and receive mode and _CS for carrier sensing. The reset is given as an active high output signal $RSTO$ and will be generated after power up, or if no negative transition on the watch-dog input _WD occurs for more than 1.5 seconds. The integrated CSMA supervision of the ST7537 avoids the blocking of the whole power-line network, which can be caused e.g. by a software bug. With a special receiving mode, the ST7537 achieves a signal gain of up to 70dB.

Measurements published by Malack and Engstrom of IBM (Electromagnetic Compability Laboratory), who measured the RF impedance of 86 commercial AC distribution systems in six European countries, have been shown that the impedance of power-lines at 100kHz can get to 1.5 $\Omega$. With the integrated line driver circuit the power-line node can drive lines with an impedance to 1.0 $\Omega$.

The ST7537 is a low-cost component and available in quantities.

4.2 Power-Line Interface

Modulated signals from the power-line modem are coupled by the power-line interface to the mains. In the other direction, signals are received by the power-line interface and demodulated by the power-line modem. For cost reduction, the power-line interface has been designed without inductive signal transformers. Thereby, the whole system is not galvanically separated from the mains and must be protected against touches.

The main component of the power-line interface is a high-voltage coupling capacitor, which has a low impedance at the centre frequency of 132.5 kHz. Additional to the mains coupling capacitor the line interface provides some analog filters to improve the quality of the receiving power-line signal.

And finally, a varistor has been added to protect the line interface and the remaining power-line node against damages caused by transients on the mains.

4.3 Power Supply

For voltage conversion, a switch mode power supply has been developed. The mains voltage of up to 250 Volts AC is divided into short sections and then smoothed to a DC voltage. The switch mode power supply provides two different voltages: 10V for the power-line modem with up to 200 mA, and 5V for the microcontroller with up to 100mA. As the power-line interface, the power supply uses for cost and size reduction no transformers and is not galvanically separated from the mains.

A high voltage MOSFET is used to switch the mains voltage for conversion. The pulse width of the switching frequency is controlled by a standard current mode FWM controller. An additional boot circuit supplies voltage to the FWM controller during start up. The operating frequency of the current mode FWM controller had to fixed carefully to prevent interferences with the power-line carrier frequency. If the fundamental harmonics of the operating frequency of the power supply avoid the centre frequency of the power-line modem, the additional interference from the switching supply can be minimized.

Inductive loads on the mains like heaters and motors may cause high voltage discharges (transients) with up to several kV. To protect the circuit from transients on the mains, a protection transil diode has been included.

4.4 Application Processor

The heart of the power-line node is a cost efficient Intel-8052 compliant microcontroller with 256 bytes of internal RAM. The current version is equipped with 32kBBytes of external ROM, which may be supplied as Mask-ROM with the microcontroller in future. Additionally, the system can be extended by a serial EEPROM of 256 bytes memory. For more demandig applications, the microcontroller can be replaced by a 8052 compliant variant with 512 bytes of RAM.

As described in the section about the power-line modem, the reset signal of the microcontroller is provided by the ST7537. This decreases the amount of external components, and in combination with the watch-dog timer of the ST7537 the insensitivity against external disturbances will be increased.

The serial interface of the microcontroller is connected to the opto-galvanically separated I/O-interface and offers up to 19.200 bauds, full-duplex asynchronous data communication.
4.5 I/O Interface

The integrated I/O interface connects the power-line node to the outside world. Two inputs and two outputs are provided with an isolation voltage of up to 5300V AC RMS. The maximum switching frequency of the optocouplers is about 20kHz. One input and one output of the I/O interface can be configured as a bidirectional, asynchronous serial interface.

The input and output levels of the I/O interface are compliant to TTL and CMOS levels.

5 Software

Most work has been spent on the software of the power-line node. A triple bit scanning algorithm with majority decision gives a very high noise rejection. Furthermore, using a special receiving mode of the ST7537 offers up to 70dB receiving signal gain. Due to a resynchronization support EHS packets with up to 3000ppm bit length difference can be received. A carrier detection provided by software allows the reception of signals below 5mVrms.

The flexibility of the power-line node is based on the EHS protocol, which defines commands for many applications in the area of heating, ventilation, air conditioning, white goods, brown goods, security, safety, comfort etc. A smart addressing scheme integrates power-line applications into a global and homogenous home automation network using various data communication systems.

The structure of the EHS protocol stack implementation complies with the well-known OSI model, without using layers 4, 5, and 6. A pseudo-parallel behaviour has been realized by a co-operative multitasking system. The „plug & play“ mechanism of EHS requires special algorithms and data structures to allow communications with devices that are unknown after power up. At first, a unique network address has to be selected by every device (registration). Then each device has to search for possible communication partners in the whole network (enrolment). Special parameters of these devices are stored together with their network address into the Application Title Directory (ATD). This very user-friendly way of installation requires a lot of expensive memory. To improve cost efficiency, the 256 bytes of internal RAM of the 8052 compliant must be sufficient. A special ATD packing algorithm has been developed to achieve this requirement.

6 Conclusion

ATICON's low-cost power-line node (Figure 3) is an universal interface for several applications in the area of home automation. Using the CENELEC C-band with CSMA collision avoidance is a prerequisite for the coexistence with other applications using the power-line medium for communication. The integrated ST7537 power-line modem offers a receiving signal gain of up to 70dB,
7 Technical Data

<table>
<thead>
<tr>
<th>Size</th>
<th>113 x 61 mm</th>
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</thead>
<tbody>
<tr>
<td>Power Supply</td>
<td>primary 110-250 V, 50-60 Hz output 10V max. 200mA, 5V max. 100mA</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>&lt;1.0 W in stand-by mode</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>-10°C...40°C</td>
</tr>
<tr>
<td>Processor Type</td>
<td>Siemens SAB C 501 LN-12, Intel-8052 compatible clocked with 11.05922 MHz</td>
</tr>
<tr>
<td>Memory Equipment</td>
<td>up to 32 kBytes external ROM 256 Bytes internal RAM 256 Bytes serial EEPROM</td>
</tr>
<tr>
<td>Protocol Stack</td>
<td>EHS 1.3 compliant</td>
</tr>
<tr>
<td>Memory Required</td>
<td>16 kBytes external ROM 256 Bytes internal RAM</td>
</tr>
<tr>
<td>Power-Line Communication Unit</td>
<td>MFSK with CSMA/CA arbitration center frequency 132.5 kHz, frequency deviation ± 0.6 kHz, output signal max. 116dB(µV) receiving signal gain 70dB</td>
</tr>
<tr>
<td>Data Transfer Rate</td>
<td>2400 bauds, half duplex</td>
</tr>
<tr>
<td>I/O Interface</td>
<td>2 galvanically separated inputs 2 galvanically separated outputs switching frequency up to 20kHz isolation voltage 5300V AC RMS</td>
</tr>
</tbody>
</table>

References

[3] EN50065-1, "Signalling on low-voltage electrical installations in the frequency range 3 kHz to 148.5 kHz", published by CENELEC, Genevra; July 1993