Konnex PL132 - Power-Line-Communication using the CENELEC-C-Band

Power-line-communication is to use the mains wiring for data communication. Because mains wiring and plugs are found nearly everywhere in every house, the installation expenses and the costs involved will be reduced, compared to other wire-bound communication solutions. This results in a very attractive alternative for the automation technology, especially for domestic applications.

This article gives basic technical information about power-line-communication and the standard Konnex PL132. Furthermore, a low-cost power-line communication module is presented, designed specially for domestic applications.

What is Power-Line-Communication ?

Using the power supply network for data communication *(Power-Line-Communication)* is not a brand new invention. Already in 1922, first carrier frequency systems for frequencies from 15kHz to 500kHz were developed in Europe, used to transmit control information by high voltage lines. Even today, power-line-communication is used by many energy providers to control e.g. street lighting or energy management systems. In private homes, the so called "baby-phones" are popular, transmitting low quality analogue voice signals via the 230V mains wiring. In contrast to the old analogue systems, digital data-transfer using the power-line as communication media is a very interesting alternative for domestic applications, particularly for those devices that are connected already to the mains (e.g. washing machines or refrigerators, linked together for energy management). Used in existing buildings, power-line communication will save the biggest part of installation costs. Hence, power-line meets the customers‘ needs for *easy-to-use* and *low-costs*.

Indoor power-line-communication may not be confused with *outdoor power-line-communication*. There are clear differences regarding the availability of frequency bands and the maximum signal levels. The indoor power-line-communication is capable to transmit data with a rate of 2400bps (bits per second), using low-cost technology. This is enough for domestic applications, because in most cases the devices have to transmit control signals only (like on/off, dimming values etc.).

Standardization of the Power-Line-Communication Media

The European Committee for Electrotechnical Standardization in Brussels (CENELEC) published the standard EN 50065-1, "Signalling on low-voltage electrical installations in the frequency range 3 kHz to 148.5 kHz " [1]. The EN 50065-1 regulates all power-line signalling within the frequency range 3 kHz to 148.5 kHz, and it has been adopted by the German Electrotechnical Commission in DIN and VDE as DIN-EN 50065-1, classification VDE 0808, as well as by many other European national committees. Four different frequency bands are specified:

- the *A-band* (3 kHz - 95 kHz), reserved for power companies,
- the *B-band* (95 kHz - 125 kHz), that can be used by all applications **without** any access protocol,

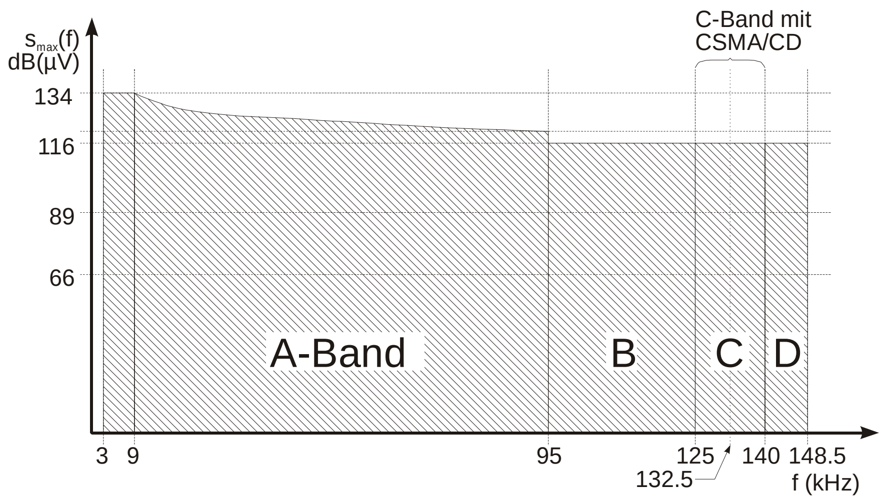

Figure 1: Maximum output level in the frequency range 3 kHz to 148.5 kHz in dB (µV)

- the *C-band* (125 kHz - 140 kHz), reserved for home network systems. A mandatory access protocol (CSMA/CA = Carrier Sense Multiple Access/Collision Avoidance) facilitates the coexistence of different incompatible systems in the same frequency band. And last but not least
- the *D-band* (140 kHz - 148.5 kHz), that is specified for alarm- and security-systems **without** any access protocol.

For all four frequency bands, a maximum output level is required by EN50065-1 for the signal transmission via power-line (*figure 1*). For the use in home network systems, the C-band with a maximum level of 116 dB (µV) is the best choice, because a media access protocol is required. The maximum output level has to be measured by a peak level detector and a given receiver circuit during a period of one minute.

Additionally, the EN 50065-1 defines noise levels for all frequency bands, mandatory for any electrical appliance connected to the mains in Europe. Thus, the potential parasitic influence by disturbances is decreased to a minimum.

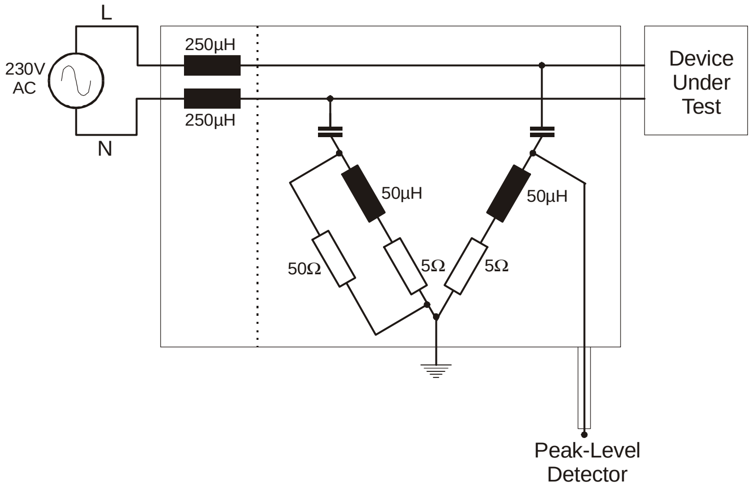

Figure 2: Measurement circuit to determine the maximum signal level

Media Access Protocol

The CENELEC C-band requires a powerful media access protocol: CSMA/CD (*Carrier Sense Multiple Access/Collision Detection*). Every sender has to check the frequency band for a certain time, before a transmission is initiated. This procedure helps to avoid collisions, appearing when two transmitters access the communication media at the same time. Moreover, the maximum transmission time is limited, ensuring the equality for all communication partners. If this time limit would be mandatory, any sender could block the frequency band permanently by transmitting data without any pause.

The media access protocol counteracts the trend that may currently be noticed in the 433MHz-ISM radio-frequency-band: Due to the complete liberalization of communication within the ISM band, different communication systems interfere each other. Considering the expected popular usage of power-line communication systems (mainly by high-end and high data-rate applications like telephone or internet services), the CENELEC-C band is the only guarantee for a cheap and reliable communication. In all other frequency bands (principally in the B and D band), the situation would probably be the same as in the mentioned 433MHz-ISM band. In this case, reliable communication systems could only be realized by high efforts, resulting costly products.

Figures 3a-c showing the rules for a media access in the CENELEC-C-band, matching the EN50065-1. The time for a complete transmission (sender A) has to be *below one second* (figure 3a). During this time, „transmission gaps“ of more than 80ms are not allowed. Otherwise, stations waiting to transmit would treat the medium for free. After the transmission, the sender has to pause at least 125ms to allow other stations to send (figure 3b). Another station may start to send promptly after 85ms (figure 3c).

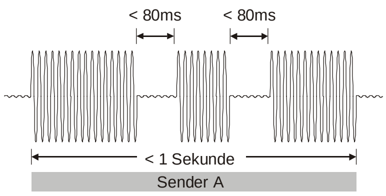

Figure 3a: Maximum transmission time

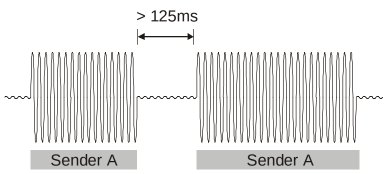

Figure 3b: Time between two transmissions initiated by the same sender

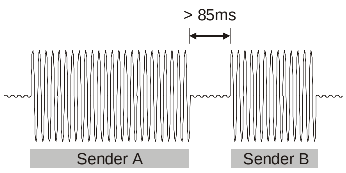

Figure 3c: Time between two sending actions for two senders

Transmission Protocols for Power-Line-Communication

The reliability of any data transmission is influenced substantially by *modulation and coding schemes*. Especially when communicating via the mains, a medium that is not specially dedicated to communication, the sensibility against disturbances could be reduced distinctly by efficient *modulation procedures*, *error correction codes* and *check sums*. According to the OSI-reference model, the physical layer and the medium access control layer (MAC) of the communication protocol are provided for all media independent services. The new *Konnex-specification* [2] has been designed for home- and building automation and defines also services for the power-line-communication using the CENELEC C-band. Beside that, also other communication media is supported, e.g. an EIB (*European Installation Bus*) downwards compatible media for installation-oriented bus systems (the so called *TP1*: TP is for *twisted pair*).

The power-line specification of the *Konnex* specification is abbreviated PL132: *PL* means power-line, and *132* is a synonym for the carrier frequency (132.5kHz, CENELEC-C band). Thanks to a wide-accepted and open standard, there is a chance to develop devices with a communication interface *without* any technological dependency to a certain manufacturer. This is a prerequisite for a free development of the home automation market and assures that the products are future-proof. All devices that comply to the Konnex specification can be integrated into existing EIB-installations by simple routers.

The CENELEC specification EN50065-1 regulates no modulation or coding schemes. This is stated by the Konnex specification. The physical layer of Konnex PL132 is based on a minimum frequency modulation scheme (MFSK). The average carrier frequency is 132.5 kHz, the modulation variation is ±0.6 kHz. A logical '1' is represented by a frequency of 131.9 kHz, a logical '0' by 133.1 kHz. Because the sender and the receiver sharing the same carrier frequency, PL132 is a half-duplex protocol. The data transfer rate is defined with 9600 baud, the maximum output level is limited to 116 dB(µV).

As usual for bus communication systems, data is composed to packages with a fixed length (telegrams) and sent via the communication media. Of course, the telegram structure has to meet the Konnex PL132 specification to ensure a correct interpretation by other communication partners.

Figure 4 shows the telegram structure of a Konnex PL132 message. In difference to other asynchronous protocols, start bits at the beginning of every byte, used for synchronisation, are missing. At the beginning of every telegram, a 16 bit preamble with 8 falling and 8 raising edges is required instead, giving the chance to the receiver for the synchronisation on incoming messages. Otherwise, possible transmit errors while transmitting a single start bit could cause a loss of synchronisation and destroy the whole telegram. The following 16 bit header is used to distinguish between telegrams (datagrams) and telegram acknowledges. Thanks to it's high redundancy, the insensibility against disturbances is improved. All following bytes are extended to 14 bit by a 6 bit-FEC code (Forward Error Correction). The generator polynomial ($x^6+x^5+x^4+x^3+1$) is correcting up to three consecutive bit errors in a sequence of 14 bits. Hence, phase-synchronous disturbances with a duration up to 1 ms, caused by light dimmers or switching power supplies, will be compensated.

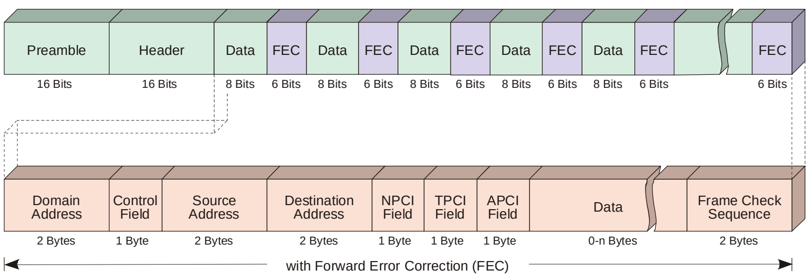

Figure 4: Structure of a power-line-telegram according to the Konnex-PL132-specification

In the first field of the telegram the 16 bit *Domain Address* is transmitted. This is necessary to separate the entire communication media into several logical sub-network areas (up to 65535), preventing reciprocal actions between different networks in the same mains wiring. The first device connected to a power-line-network chooses the domain address and passes it to devices that are installed afterwards.

The *Control Field*, following the domain address, transmits among other things a flag separating the whole address space into *group addresses* and *individual addresses*. Group addresses are used to transmit control operations at the systems runtime, like switch on and off. Individual addresses are used for the system configuration only. The next two data fields transmitting the *Source Address* and the *Destination Address.* The following NPCI-field (NPCI = *Network Layer Protocol Control Information*) contains the length of the data area and a counter to limit the number of message forwards via routers. The TPCI-field (*Transport Layer Protocol Control Information*) is used for connection oriented communication (OSI layer 4). The succeeding data area transmits at first a control byte (APCI = *Application Layer Protocol*

Control Information) and then up to 14 bytes of data.

The last field of power-line telegrams is a 16 bit frame checksum (*FCS*), that assures the consistence of the entire telegram. The generator polynomial is given by $x^{16}+x^{15}+x^2+1$. Thus, transmission errors are prevented with a high reliability.

The FCS is returned from the receiver to the sender as an acknowledge after receiving a telegram correctly.

Cost-Optimized Power-Line Communication Modules

The power-line communication technology from DOMOLOGIC Home Automation, integrates a *power-line modem*, *power-line interface*, *energy supply*, *microcontroller* and an optogalvanically isolated *I/O-interface* on a small printed circuit board of only 50x80 mm. *Figure 5* shows the block diagram of a power-line communication unit. The galvanically isolated I/O-interface provides the connection to the outside world. Two inputs and two outputs are available with an isolation voltage of up to 5300 $V_{AC\ RMS}$. The isolation is necessary, as the core of the communication unit is not galvanically isolated from the mains. The inputs and outputs are compatible to TTL- and CMOS-voltage levels, and dimensioned for signal transfer rates of up to 19200 baud. In the following, all parts of the circuit will be described in separate sub-chapters.

Power-Line-Modem

The entity *power-line modem* modulates and demodulates the carrier frequency, monitors the media access protocol and generates clock and reset signals for the microcontroller. Furthermore, it provides a watchdog circuit to the microcontroller, what reduces the number of components and the costs. The power-line modem was designed around the Konnex-compliant integrated circuit *ST7537HS1* from ST Microelectronics [4], that is low-priced and available in high quantities. The circuit complies with the Konnex specification, offering a transfer rate of max. 2400 baud. The interface between the microcontroller and the ST7537HS1 is pretty simple and realized by only four signals: *Tx* for outgoing data, *Rx* for incoming data, *Rx_/Tx* for shifting between send- and receive-mode, and finally */CS* as a carrier frequency indicator (*Carrier Sense*).

In a special receive mode, the signal gain of the ST7537HS1 is about 70 dB (amplifying the signal by a factor of more than 3000). The clock-frequency of 11.05922 MHz can be realized by a simple quartz oscillator.

Field tests made by *Malack* and *Engstrom* (IBM Electromagnetic Compability Laboratory), who measured the RF impedance of 86 commercial and private AC distribution systems in six European countries, have been shown that the impedance of power-lines at a frequency of 100kHz could be below 1.5Ω. This value is caused mainly by the connected electric power consuming devices and the internal resistance of the transformers. In consideration of this low impedance, the driver of the power-line modem is dimensioned to drive power-line networks with an impedance of down to 1Ω.

Power-Line-Interface

The signals coming from the power-line modem are coupled capacitively into the power supply network by the power-line-interface. Reversionary, the signals filtered from the mains are getting to the power-line modem via the power-line interface. To optimize component costs, the circuit has been designed without any inductive signal transmitters. That's why this entity is not galvanically isolated from the mains. A varistor protects the circuit from peak voltages on the power supply network, caused by inductive loads (e.g, electrical heating devices or motors).

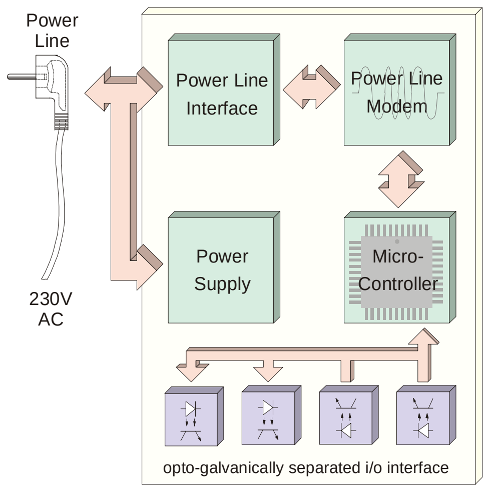

Figure 5: Block diagram of the power-line communication unit

Power Supply

The integrated power-supply of the communication unit is realized by a specific *Step-Down-Converter*, that transforms the input voltage (up to $250V_{AC}$) to 10 V_{DC} (up to 200mA). An associated linear voltage regulator supplies the digital part of the circuit with $5V_{DC}$.

By avoiding any inductive transmitters for the power supply, production costs have been reduced furthermore. The direct connection of the power supply and the power-line interface to the mains wiring does not cause any disadvantages.

The power supply was dimensioned to supply the power-line modem with enough power, even when the impedance of the mains is as low as 1Ω. Additionally, the switching frequency of the power-supply avoids the fundamental harmonics of the power-line communication to minimize any interference.

Microcontroller

The heart of the power-line communication module is an

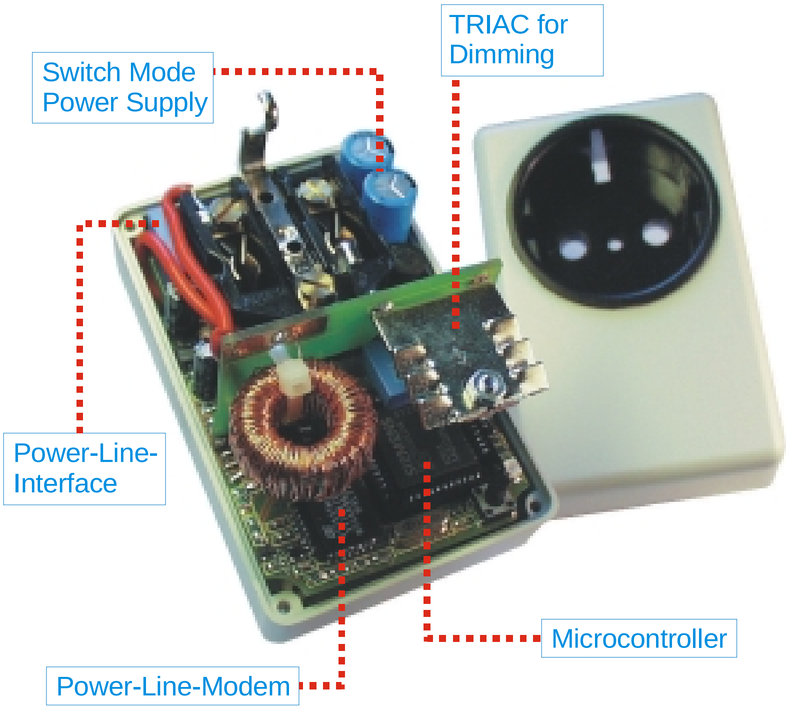

Figure 6: Remote-controlled intermediate plug for power-line-communication

Intel-8052 compliant microcontroller with 256 bytes of internal RAM and 8kBytes FLASH memory. Additionally, 256 bytes of EEPROM are provided for configuration data (serial number, individual address etc.) The microcontroller communicates with the application and is responsible for all communication. As already mentioned in the sub-chapter of the power-line modem, both, the clock and the reset signal are generated by the power-line modem, reducing the need for additional components. Therefore, the system clock of the microcontroller is fixed to 11.05922 MHz.

I/O-Interface

Galvanically isolated outputs are connecting the power-line communication module to the application. There are two inputs and two outputs available, providing an isolation voltage of up to 5300$V_{AC\ RMS}$. The isolation is absolutely necessary as the core of the module is isolated from the mains. The inputs and outputs are TTL- and CMOS-compatible and capable for signal transfer rates of up to 19200 baud.

Remote Controlled Plugs

Figure 6 shows the integration of a power-line communication module in a remote-controlled plug. Instead of the opto-galvatically isolated I/O-interface, a zero crossing detector and a TRIAC are connected to the circuit. Implementing a phase controlled modulator, the light of a lamp plugged in can be changed within the range from 0-100% in steps of 1%.

Software for Power-Line-Communication

Generally, much more development effort is required for the software of communication systems than for the hardware. The software is necessary to perform mainly the following tasks:

- to process messages, received by the communication media (power-line),
- to transmit messages to the communication media,
- to control the application hardware, e.g. to switch relays or to measure temperatures,
- to provide some basic system functionality (system management), like updating a watch-dog, managing non-volatile memory etc.

Regarding the power-line communication modules presented here, the software is processing all messages in a Konnex-PL132-compliant way and in both directions (sending and receiving). This work is done by the so-called *protocol stack*. A structured overview of the software is given in figure 7. The protocol stack is designed according to the OSI-7 layer model, implementing layers 1-4 and layer 7. The layers 5 and 6 are not required due to the Konnex-specification. In the receiving direction, telegrams received via the power-line are transferred step by step from the lowest layer (Physical Layer) to the upper layer (Application layer). For sending, the telegrams are pushed in the opposite way. Additionally to the protocol stack,

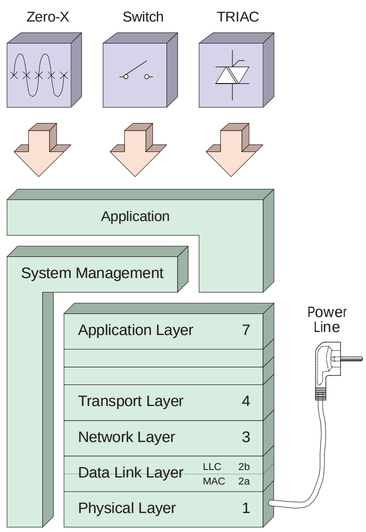

Figure 7: Power-Line-Communication software

a system management module is provided to manage addresses and to configure the protocol stack.

Both software modules, the protocol stack and the system-management, are equal for all power-line devices. For example, a remote-controlled dimmer, a communicating dish washer or a fridge are using copies of the same protocol stack and the same system management module. The only difference is the individual application software of the device. Well-defined *Application Program Interfaces* (APIs) to the protocol stack's upper layer and to the system management module are establishing the connection.

The application's task is to handle the hardware, connected to the communication module. Messages received by the protocol stack, dedicated to the communication module, are interpreted by the application software and transferred into output actions, e.g. switching relays or measuring temperatures. In the case of a successfully received telegram, the application software is notified by the API. In the reciprocal way, actions at the inputs of the communication module are detected by the application software that initiates the protocol stack to transmit a message. When the transmission of the telegram is completed, the application will be informed via the API by the protocol stack, whether the transmission was successful or not. In the example of the light dimmer, the application realizes a phase controlled modulator, using an external zero-crossing detector and the TRIAC. A local on/off switch is used for manual control. New messages, received by the protocol stack, affecting the phase controlled modulator to modify the light level.

Conclusion

Because of the easy installation process, power-line-communication is a very attractive media for home and building automation. Many applications wouldn't be taken into account by the end-consumer, if special control wires had to be installed. For instance, the possibility to control a heating system via the television or a central control terminal would be a promotional argument, but high installation expense and costs would block a successful commercialization. For the same reason, communication modules require an extensively smart protocol, that supports an easy installation procedure. Thus, components are installable without the need for experts. The new Konnex-standard provides a protocol for these scenario (*Auto Configuration*). Moreover, the cost-effective realization of communication modules is an important precondition for the end-consumer market.

Literature

1. EN50065-1; „Signalling on low-voltage electrical installations in the frequency range 3 kHz to 148.5 kHz"; CENELEC; Genevre, July 1993
2. "Konnex Specification 1.0"; Konnex Association; Brussels 2000
3. "Home Systems Specification 1.3"; European Home Systems Association; Brussels, 1996
4. "Power-Line Modems & Applica-tions"; ST Microelectronics; May 1994