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Description of the Technology and Comparison of the Performance of two different Approaches for a Powerline Modem in the CENELEC-Band

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Abstract

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The first generation of PolyTrax-PLC-modems, using conventional FSK-modulation, and the second generation, using OFDM-QAM-modulation, are both in the production state today. The technology is briefly introduced, with an emphasis on the more modern, second approach, which has built-in dynamic frequency allocation and automatic channel adaptivity. After a short description of the powerline-characteristics in the European CENELEC bands B and D for Inhouse communication, the performance of both solutions and the results of field-tests are compared. The additional features of the third generation of PolyTrax-PLC-modems, which is already in the lab-prototype stage, are given.

1. Introduction

Today the European CENELEC-standard allows powerline communication (PLC) for Inhouse applications in the B-band from 95 kHz to 125 kHz and in the D-band from 140 kHz to 148.5 kHz. The C-band, which is between B and D, is also allowed for Inhouse use, but a specific multiple access protocol should be used. Thus a total bandwidth of 38.5 kHz is left for Inhouse PLC without a fixed protocol. The CENELEC standard defines 116 dBμV as maximum transmitter-voltage, measured with a specific impedance-model for the powerline-network. Within these boundaries PolyTrax has developed two types of PLC-modems respectively PLC-transceivers: A low speed version with robust transmission for home-automation and -control and a medium speed version for in-house communication. The first modem uses Frequency Shift Keying (FSK). The second one is based on Orthogonal Frequency Division Multiplexing (OFDM); main applications in the immediate future are Inhome-pc-networks, Internet access, telephone access from every room of the house, back channel for set-top-boxes and music distribution via powerline.

2. The FSK Approach

The modem uses a special burst error correction, called Hagelbarger coding, with relative low code rates. The coded data (with protection via checksum) is modulated with binary FSK (BFSK), which has the advantage of a constant envelope of the transmitted signal. Thus the receiver front-end is a simple limiting amplifier. An FSK-modem is easily implemented in hardware (Fig. 1): the ports of a microcontroller are used for serial/parallel data exchange and a Direct Digital Synthesizer (DDS) generates the analog output signal. The FSK signal is demodulated by analysing the timing of the signal transitions, produced by a comparator, who works as a zero-crossing-detector.

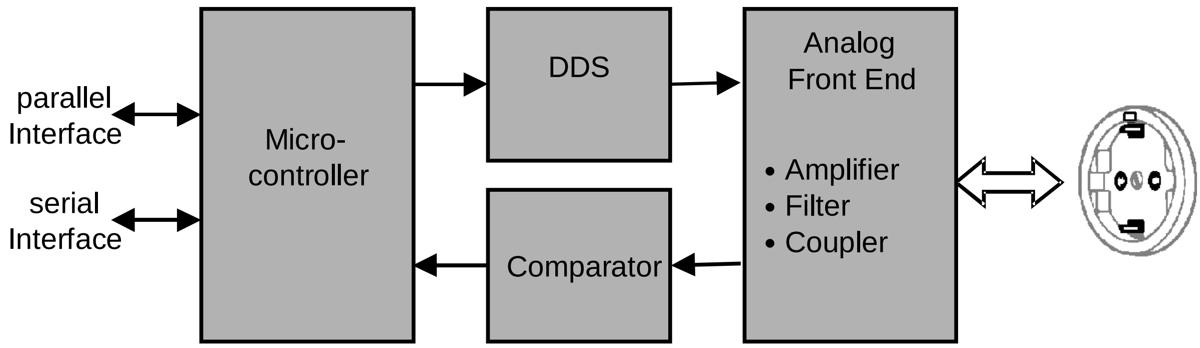

Fig. 1: Hardware architecture of the FSK-modem

The FSK-modem uses the B-band only. Maximum transmission speed is 25 kbit/s. In case of low signal-to-noise ratio (SNR) the user can switch to three consecutively more robust coding schemes with consecutively lower transmission speeds. Each data-package carries the address of the receiver, who should get it. Package length is chosen dynamically, disturbed packages are automatically retransmitted.

3. The OFDM Approach

3.1 Channel Coding, Modulation and Equalization

BCH coding for forward error correction (FEC) was chosen, because it offers a significant performance gain even with high code rates, while not reducing the data rate too much. The BCH code is decoded very efficiently by the use of look-up tables.

The subcarriers are modulated with Quadrature Amplitude Modulation (QAM). QAM signal constellations can be easily demodulated with uncomplicated decision regions.

A frequency-domain equalization is applied to correct phase and amplitude deviation of each subcarrier due to linear channel distortions. The taps of the equalizer are adjusted during a training period at the beginning of each super frame.

3.2 Bit loading and Power loading

The training period is also used for channel estimation, i.e. the SNR of each subcarrier is determined. After the channel analysis, information and power is assigned individually to each subcarrier according to its SNR value; more information is assigned to subchannels which reveal less attenuation and disturbance and vice versa.
The objective of the bit loading algorithm is to maximize the total data throughput, for a given error rate, total transmit power and the measured SNR. This is achieved by rate allocation based on the channel capacity of every single subchannel. The power is assigned in a way that symbol error probabilities for all subcarriers are equal.

3.3 Frequency Bands

The Discrete Multitone (DMT) solution has the advantage, that even very small frequency bands, being assigned to PLC-usage, can be used very efficiently. Thus today the B-band and the D-band are used in this modem, with the result of a transmission speed of 150 kbit/s for an SNR of 25 dB.

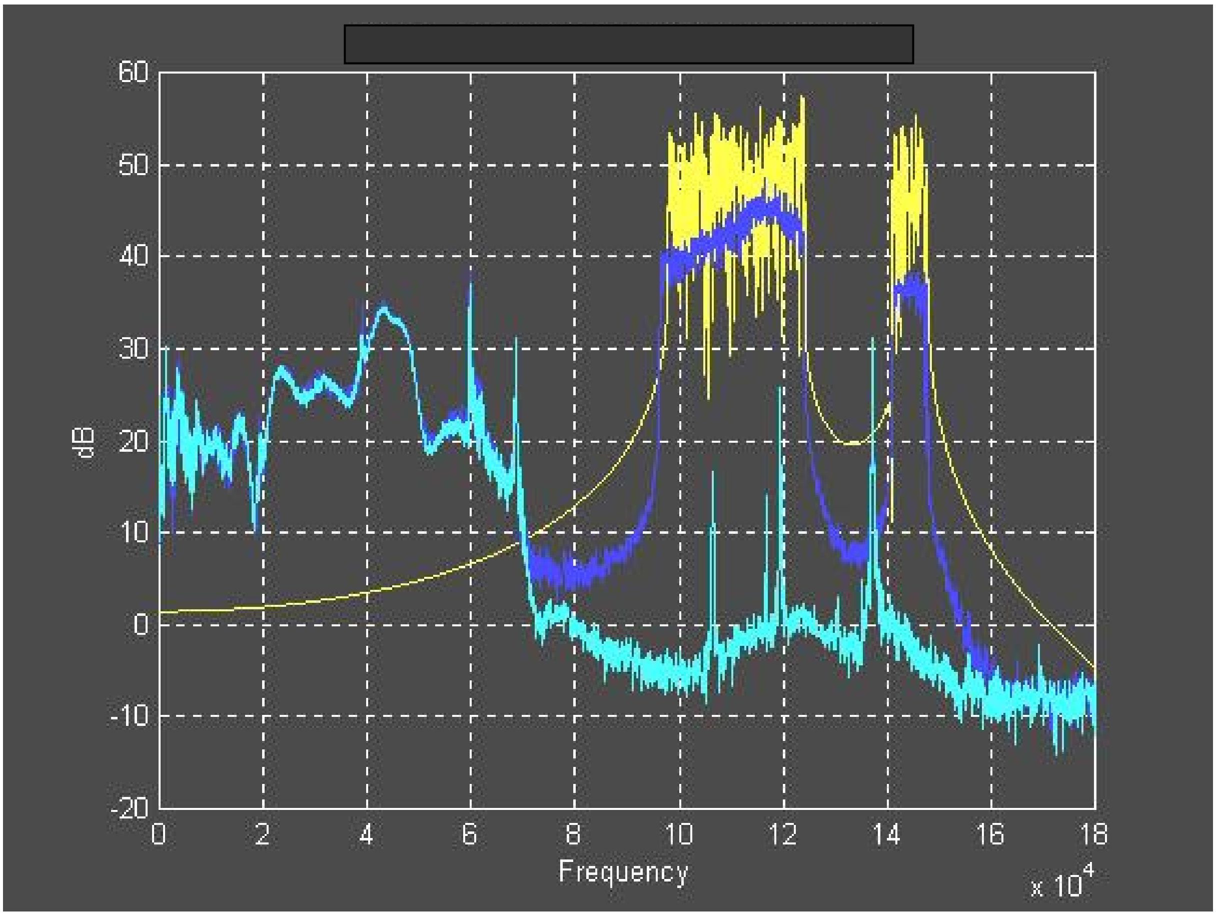

Fig. 2: Transmitted and received signal, noise, typical SOHO environment

3.4 Synchronization

Frame synchronization of super frames is achieved by energy detection which is remarkably immune against linear and nonlinear distortion. For timing synchronization, the phase of a pilot tone is detected in order to correct the individual phase offset of every subcarrier. Frequency synchronization is not necessary, due to the accuracy of the used quartz oscillators. Because the transmitted signal stays in the base band, problems with PLL synchronization are avoided.

3.5 Hardware Architecture

Most of the modem operations are implemented as software. Nevertheless, the hardware architecture is regarded in Fig. 3. The heart of the modem is a state-of-the-art Digital Signal Processor (DSP). Only few additional circuitry is necessary for the modem (which is neglected in the figure). A variety of interface devices can be connected to the DSP, some of them are shown in the picture.

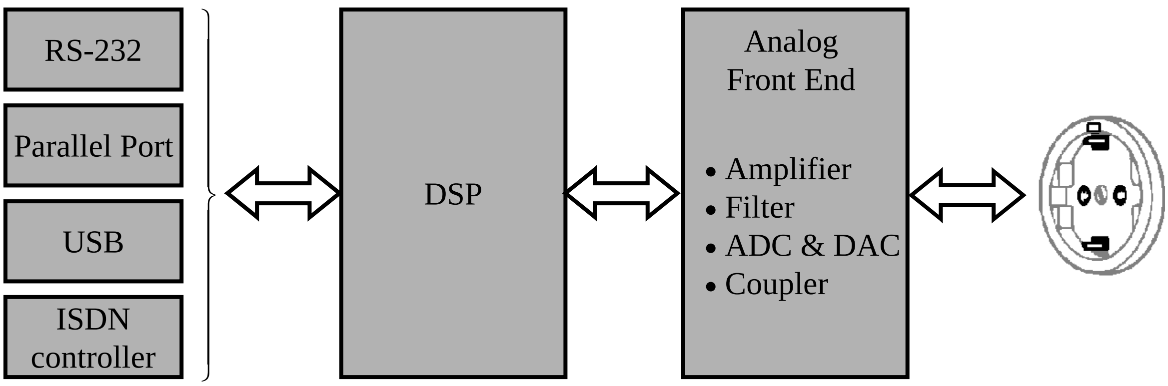

Fig. 3: Hardware architecture of the OFDM-modem

The transmission signal is generated inside the DSP with an inverse Fourier-Transform (IFFT); after D/A-conversion, lowpass-filtering and amplification it is coupled to the powerline. For reception the incoming signal is bandpass-filtered, amplified and A/D-converted. Then the DSP extracts the different carriers by calculating the Fourier-Transform (FFT). Data packages with more bit errors than the FEC can correct, are automatically retransmitted (Automatic Repeat Request, ARQ-protocol).

3.6 Integrated Adaptivity

The dynamic frequency allocation can also be used to detect other PLC-systems. In the same way as discrete interference signals are treated, these frequency bands will be left out in the transmission signal.

Depending on the actual SNR on the powerline, the modulation is switched down from a 64 QAM, with very fast transmission rates, to a 16 QAM, then to QPSK and if necessary to an even more robust modulation scheme, that uses higher power levels. This scheme is also used to make the initialisation-communication in an Inhome-network. As soon as the disturbances cease, transmission speed is automatically shifted upwards again.

The software-based DSP-solution for this PLC-modem is a very flexible approach. Besides the described possibility to automatically adapt to the channel characteristics, the user is able to update the software without a hardware change whenever it is necessary. A remote update via Internet or PC is also optionally possible. For instance whenever the regulations are changed, new frequency bands can be added or cut out. The transmitter level can also be changed by software.

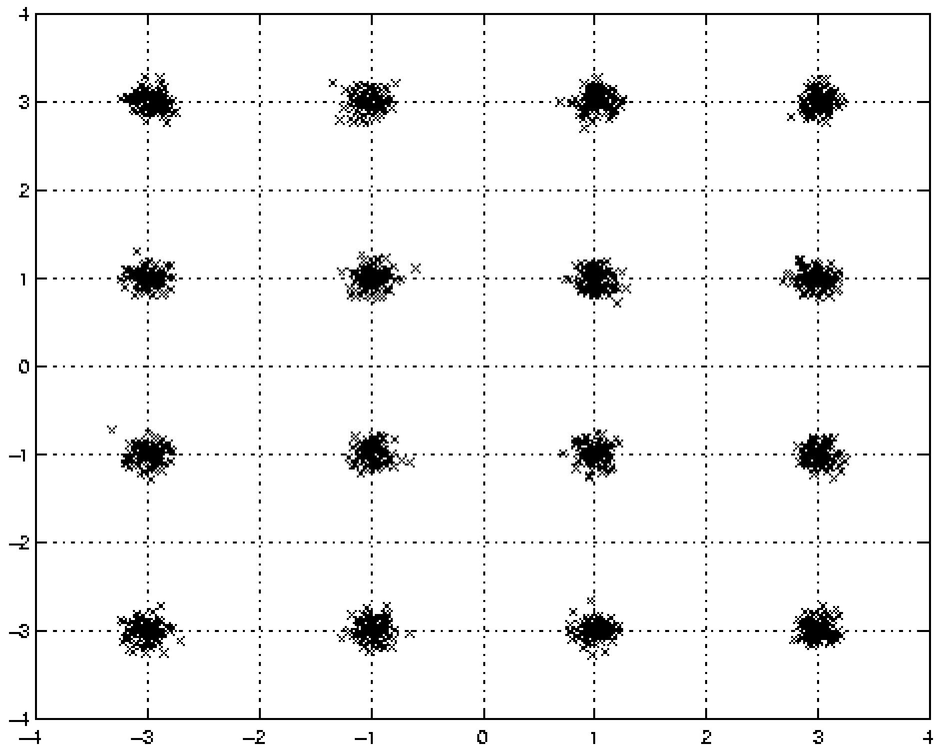

Fig. 4: 16 QAM constellation diagram

4. Channel Characterization

Below 150 kHz multipath effects, reflections and radiated fields are negligible for Inhouse-PLC. Typical powerlines, looked at as homogeneous TEM-waveguides, have an attenuation of less than 1 dB/km. Therefore the attenuation of a PLC-signal in such systems is only depending on the topology and the loading of the line. Actually it is the voltage divider built by the inductance of the line and the load that produces attenuation. With an inductive impedance of for instance j1 Ω/m, there will be 20 dB of attenuation with 10 m powerline terminated by 1 Ω. If this type of voltage divider is cascaded several times, the result is quite a lot of attenuation over all.

Such low loads are never 50-Hz-loads but they are capacitive loads, for instance from switched power supplies or dimmers. The combination of distributed line inductance and load capacitance results in strong dependencies of attenuation from frequency. Besides the channel characteristic varies (with time) during the day, depending on the various loads, being switched on and off the powerline.

The powerline as communication channel is characterized by an impedance in the range between 1 Ω and 100 Ω, varying with time and with frequency. Furthermore there is a high level of interference signals, impulse disturbance and switching noise, well above the thermal noise level. Devices that contribute most to this high disturbance level are switching power supplies, monitors (CRT's), inductive heaters, dimmers, radio stations and frequency converters.

5. Comparison of both modems

High volume production costs are the same for both modems. The possibilities of integrated adaptivity and spectrum management are much more powerful with the OFDM-approach.

Extensive field tests have shown that the FSK-modem with a dynamic range of 60 dB has a coverage of approximately 98% of all power outlets in private houses and apartments. The OFDM-modem, with 80 dB dynamic range, covers 100% of all power outlets in an Inhouse environment. There is a stable data transmission from every power outlet to all other power outlets in the powerline network.

In case of high attenuation, extensive noise level or data transmission between two outlets connected to different phases (without phase-coupler) the average data rate may decrease to 100 kbit/s, because the 16 QAM is used on all carriers instead of the 64QAM.

6. Future Developments for both Modem-Types

The FSK-modem will in the future only be supported in those home-automation and -control applications, where it has been brought into the market in high volumes.

The third generation of PolyTrax-modems will be OFDM-modems for use outside Europe in the frequency range up to 500 kHz, with an average transmission speed of 2.5 Mbit/s. They are based on the same hardware as those for Europe. The higher speed results from the larger bandwidth available for PLC-use outside Europe, there are no other technical reasons for this.

Channel coding and adaptivity will be further improved and a novel error correction code will allow reception of uncorrupted signals down to an SNR of -3dB. For specific applications costs will be cut down even more by sharing the same DSP for various additional tasks, e.g. V.90-modem, MP3-codec or USB/ISDN-traffic-coordination.

All this will help to make powerline communication a solid and reliable branch in the fast growing tree of modern communication solutions.

Fig. 5: Lab-prototype of OFDM-modem