Power-Line Communication - Regulation Introduction, PL Modem Implementation and Possible Application

Zdeněk Kašpar

Motorola Czech Systems Laboratories,
1. máje 1009, 756 61 Rožnov p.Radh., Czech Republic,
E-mail: zdenek.kaspar@motorola.com

Abstract: *In this article a brief introduction to low speed power-line communication (PLC) is presented including the regulation basics and regulation-related issues in different markets. A particular low-cost low-speed power-line modem (PLM) implementation based on a Digital Signal Processor (DSP) is described together with its development history. And finally, a possible real world PLM application is shown.*

I. Introduction To Power-Line Communication

The idea of using the power-line (mains) wiring infrastructure as a communication medium is very old. It is quite easy to find out why - it has the most ubiquitous coverage of any other possible media. It is almost sure that you can find at least one or two power outlets in every room of your house. And according to the phrase “no new wires to your homes”, this is a very low cost solution.

On the other hand, the power-line medium is a harsh environment for communication. The channel between any two outlets in a home has an extremely complicated transfer function with many stubs having terminating loads of various impedances. Such a network has an amplitude and phase response that varies widely with frequency. At some frequencies the transmitted signal may arrive at the receiver with relatively little loss, while at other frequencies it may be driven below the noise floor. Worse, the transfer function can change with time. This might happen because the homeowner has plugged or unplugged a device from the power-line, or if some of the devices plugged into the network have time-varying impedances (which can be the case with switching power supplies or motors).

As a result, the nature of the channel between outlet pairs may vary over a wide range. In addition to the transfer function problem, and equally significant, interference over the power line must be considered. The most severe interference sources rarely have properties similar to easily-analyzed white Gaussian noise. Instead, the interference can be either impulsive or frequency selective in nature, and sometimes both.

Typical sources of noise are brush motors, fluorescent and halogen lamps, switching power supplies and dimmer switches. The net impact of these different interference sources is that received raw data bits tend to have significant numbers of bit errors, which must somehow be corrected. These are the main obstacles of PLC and they all have to be considered.

II. Regulation Basics

The European PLC regulation norm is called CENELEC EN 50065-1: “Signaling on low-voltage electrical installations in the frequency range 3kHz to 148.5kHz” [1]. It defines the allowed frequency ranges of power-line communication, maximum signal amplitudes, as well as the limits of the interference to the surrounding frequency bands. The frequency range division is shown in Table 1.

Band	Frequency range	Purpose
	3 kHz - 9 kHz	for electric distribution companies use only
A	9 kHz - 95 kHz	for electric distribution companies use and their licenses
B	95 kHz - 125 kHz	available for consumers with no restriction
C	125 kHz - 140 kHz	available for consumes only with media access protocol
D	140 kHz - 148.5 kHz	available for consumers with no restriction

Table 1: Frequency ranges according to CENELEC EN 50065-1

Maximum output levels in the range from 9 kHz to 150 kHz for a single phase-device is shown in Table 2. Measurement has to be done according to the CISPR 16 publication (quasi-peak detector, 1-minute long measurement at specified points on the CISPR artificial network).

Frequency range	Maximal transmission level	Type of devices
3 kHz - 95 kHz	134 dB (μV)	
95 kHz - 148.5 kHz	116 dB (μV)	general purpose devices
95 kHz - 148.5 kHz	134 dB (μV)	special devices (such as industry applications)

Table 2: Frequency ranges according to CENELEC EN 50065-1

On the other hand, the US FCC Part 15 standard defines the available frequency range much wider, as shown in Figure 1. The reason is that the LW radio transmission range is not used in the North America.

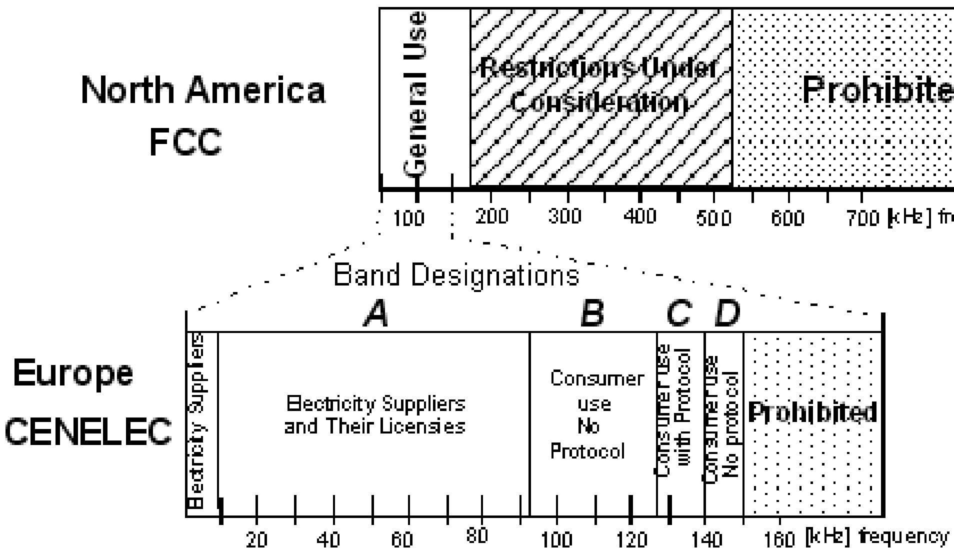

Figure 1: North America vs. Europe regulation in the area of PLC

The CENELEC norm defines neither a data rate nor a modulation scheme, but because of the quite narrow frequency range of each band, only relatively low data rates are possible.

III. PLM Development And Implementation

The objective was to implement a low-speed (10 kbps) low-cost PLM working in half-duplex mode using a 16-bit DSP (Motorola DSP56F801 with 40MIPS, see [2] for more details) communicating in the CENELEC "B" band (95 kHz - 125kHz) using a *frequency shift* *keying (FSK)* modulation scheme. The so-called *transparent channel* or *transparent mode* of the packet-oriented protocol had to be implemented.

The transmission had to be secured using *forward error correction (FEC)* combined with the *interleaving technique*, 16-bit *Cyclic Redundancy Code (CRC)* and also encrypted using the *Tiny Encryption algorithm (TEA)*. These algorithms are not a topic of this paper, see [4] for more.

Two different approaches were taken. The first one, utilizing the external components for the FSK modulation / demodulation while the DSP serves only as a very fast controlling unit, is shown in Figure 2.

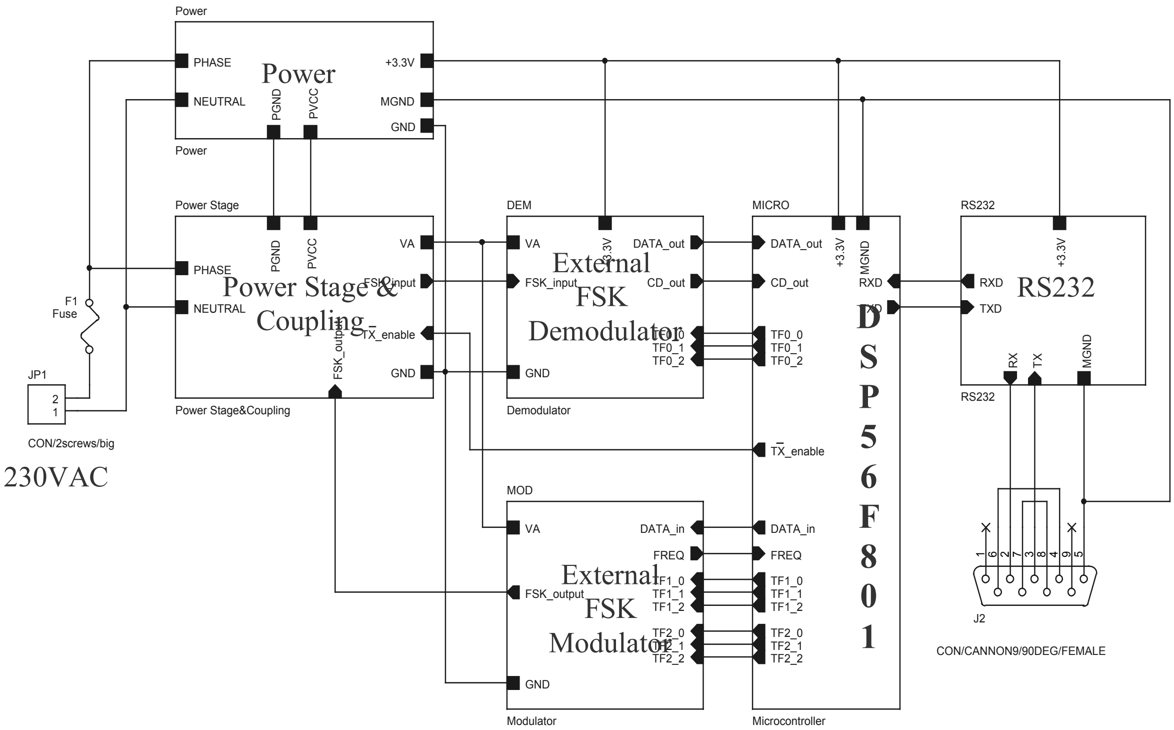

Figure 2: Block diagram of the PLM

Although as far as a 20 kbps bit rate was achieved while still having enough DSP computation time available for a possible application, finally, the second approach, which fully utilizes the DSP with both FSK modulation and demodulation, was chosen.

It can be said that the block diagram of the resulting PLM is similar to the one shown in Figure 2, knowing that external modulator / demodulator blocks are replaced by s/w routines supported by an output filter (for the FSK modulator) and an input stage (for the FSK demodulator). The most crucial part, the FSK demodulation algorithm, is described in [3].

The main advantages of this solution are:

- Modulation / demodulation frequencies are not determined by hardware parts (not wired). They can be freely set in source code according to the user’s need.
- Better functionality and reliability (e. g. better packet error rate, longer possible communication length) since the demodulation algorithm is not as affected by noise like the external hardware demodulator.
- A cheaper solution (majority of the external components are eliminated).

IV. RESULTS

My experience from the development is that it is very complex to make the proper measurements in such a harsh and noisy environment (with impulsive interference peaks, some frequency interference) as the power-line. The results of measurement change very rapidly in time since the parameters of the mains change. So a lot of measurements and statistics should be used during the measuring phase.

To sketch at least some parameters of the current PLM solution:

- Two PL modems were able to communicate with each other up to about 150 m in the environment of the motor control oriented laboratory; this distance is quite enough for home automation while still not sufficient for industry applications.
- The packet error rate (number of bad packets to total number of packets ration calculated over approx. 3000 packets, each 32B long), measured using two PLMs with an attenuation module connected to the CISPR (50 Ω / 50 μH + 5 Ω) artificial network, is shown in Table 3. These values give a rough indication of the reliability of the PLM.

Attenuation [dB]	0	-10	-26	-46	-65
Packet error rate	2.60E-03	2.90E-03	2.70E-03	2.80E-03	7.30E-03

Table 3: Packet error rate measurement

A PLM concept was also succesfully tested on the application based on the EMIT technology (Embedded Micro Internetworking Technology) by emWare; see [6] for more. The EMIT is a system allowing micro-controllers to connect to the Internet in a normal "wired" fashion. So a necessary modification of the EMIT structure was done first. The communication cable (either RS232 or RS485) between the gateway (controlling device) and the microprocessor (end-device) was replaced by a pair of PL modems.

VI. Conclusion

It seems that the idea of a higher-speed power-line communication (e.g. audio / video on demand, Internet access) under the current European CENELEC EN 50065-1 regulation is quite unrealistic. On the other hand, lower and middle baud rates (units up to tens of kbps) are practical even under the present rules, possible to implement, and relatively low-cost.

When producers and developers find and settle on a proper communication protocol (an organization called Konnex and their standard [5] is getting more and more respect in Europe nowadays), it will just be a question of time when they also find a proper use for this technology, probably in areas like metering, home automation, fire and security, and so on. The first steps can even be seen today.

References

[1] CENELEC EN 50065-1: "Signaling on low-voltage electrical installations in the frequency range 3kHz to 148.5kHz", 1991

[2] Motorola Inc.: "DSP56F80x User's Manual", Motorola User's Manual, 2000, http://mot-sps.com/

[3] Milan Brejl: "FSK Demodulation on DSP", Radioelektronika 2002, accepted

[4] Motorola Inc.: "Reference Design Manual - Power Line Modem", Motorola Reference Design, 2002

[5] Konnex Organization: "Konnex specification version 1.0", http://www.konnex-knx.org/

[6] EmWare: "Embedded Micro Internetworking Technology", emWare Inc., http://www.emware.com/

[7] Steve Gardner, Brian Markwalter, Larry Yonge: "HomePlug Standard Brings Networking to the Home", http://www.csdmag.com