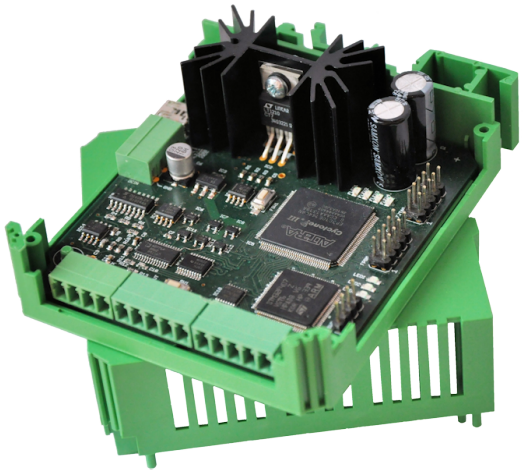
MULTICARRIER POWER LINE COMMUNICATION MODEM



Advanced Radio Systems, s.r.o.
U dálnice 2724, 155 00 Prague, Czech Republic
email: info@radiodev.eu

Outline

1 Product overview

2 Product description

3 Product evolution and comparison

Comparison of MCM techniques: FDM vs. OFDM

- **Orthogonal frequency-division multiplexing (OFDM):**
  1. Advantages: **high spectral efficiency**; extreme resistance to multipath propagation.
  2. Disadvantages: block oriented processing with **high proccessing latency**; **cyclic prefixes** are necessary; **high Peak-to-Average Power Ratio (PARP)**.
- **Frequency Division Multiplexing (FDM):**
  1. Advantages: **medium or low PAPR**; continuous processing without significant latency; cyclic prefix insertion is not required.
  2. Disadvantages: **less spectral efficiency** and less resistance to multipath propagation.

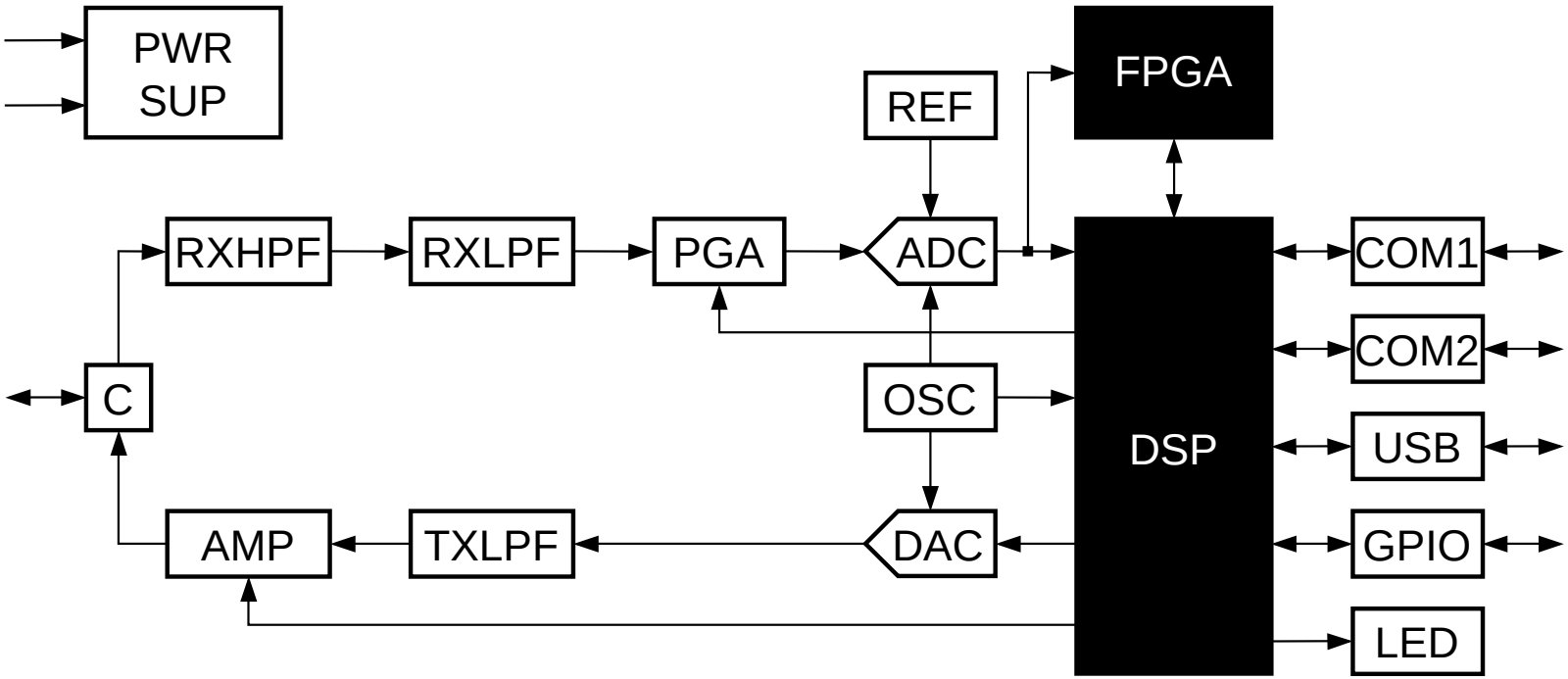
Key features

- **FDM** of narrowband **trellis coded linear digital modulations (TCM)** using **square root raised cosine modulation impulse** with roll-off factor 0.4 and **constellation QPSK**.
- **Bandwidth 96 kHz divided to 16 subchannels** centered on frequencies 30, 36, 42, 48, 54, 60, 66, 72, 78, 84, 90, 96, 102, 108, 114 and 120 kHz. **Subchannel bandwidth is 5.5 kHz**.
- **Flexible thread allocation** unit **allows arbitrary merging of subchannels** for particular user data streams.
- Modular design allows easy adaptation for many purposes. **Mounting in standardized DIN rails**.
- Seamless interconnection between modem and computers or sensors.
- **The primary area of use is smart grid networking transmissions**.
- **Network topology** is assumed as **POINT2POINT**, **POINT2MULTIPOINT** with **master/slave management**.

Areas of usage

- **Smart Grids**
- Internet of Things
- Controlling of power distribution grid
- Optimization of power distribution grid
- Automatic Meter Reading, Billing
- Anti-theft monitoring
- Remote controlling
- Advanced Metering Management, Advanced Metering Infrastructure

Hardware design (1)

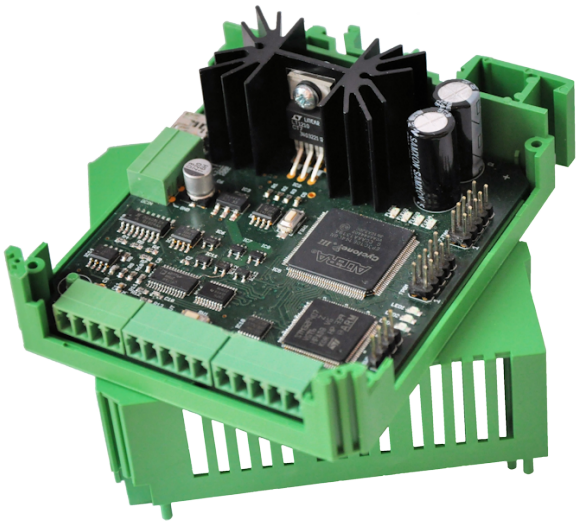


Modem block diagram.

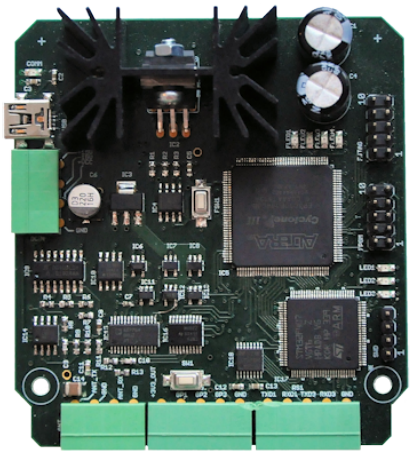
Hardware design (2) and Firmware

- **Sampling frequency: 250 kHz**; -3 dB bandwidth: 3-150 kHz
- RMS/Peak output power: 9W/29W
- Power consumption of receiving: 3W
- Mounting box: IP20, 45 mm width
- **Firmware**
  1. **DSP algorithms:** source code in Verilog HDL, targeted to Altera FPGA Cyclone III.
  2. **Modem control:** source code in C, targeted to ARM microcontroller or any processor.

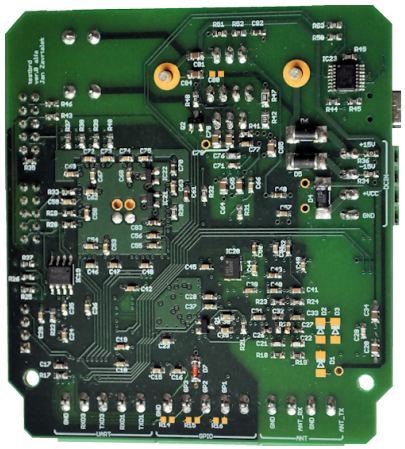
Prototype snapshots



Side view.



Top view.



Bottom view.

Physical layer (1)

- **First L1 firmware (alpha version):** complete L1 without channel encoders and decoders; released in August 2016.
- **Transmitting front-end:** pulse shaping filter (interpolation FIR filter), linear interpolator, up-converter, RF signal buffer and step amplifier.
- **Receiving front-end:** RF signal buffer, down-converter and down-sampling cascade of three decimation FIR filters.
- **Channel synchronizer:** automatic gain control (AGC), complex Costas loop and phase ambiguity domain synchronizer.
- **Frame synchronizer:** pair of correlators (binary and fine) and threholding block.
- **Soft-output demodulator**

Physical layer (2)

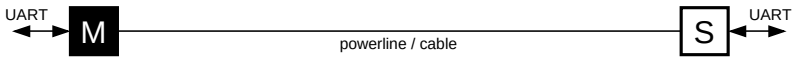
- **Second L1 firmware (beta version):** complete L1 with trellis channel encoders and decoders; going to be released in September 2017.
- **Encoders:** two trellis encoders with code ratio 1/2; feedforward 1st order (two states) binary code and feedback 2nd order (four states) binary code
- **Decoders:** soft-output Viterbi algorithm with fixed lag (FL-SOVA).

System variant	Packet length [bits]	Preamble length [bits]	Alphabet	Subchannel bitrate [kbit/s]	Modulation bitrate [kbit/s]	User data bitrate [kbit/s]	Usage
Trellis code 1/2 protected	1024	32	QPSK	3.9	62.4	60.5	LOW SNR $>$ 4 dB
	2048	32	QPSK			61.5	
	4096	32	QPSK			61.9	
Uncoded	1024	32	QPSK	7.8	124.8	120.9	HIGH SNR $>$ 10 dB
	2048	32	QPSK			122.9	

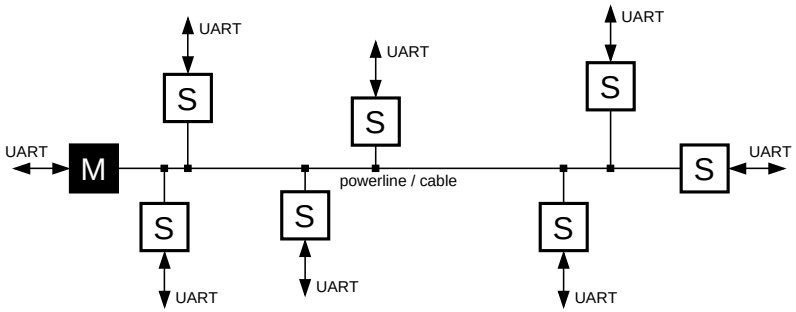
Bit rate upperbounds.

Link layer

- **Master/Slave** communication principle applied to **POINT2POINT** or **POINT2MULTIPOINT** topology.
- **Half-duplex** transmission, **Proprietary protocol** and **Serial port** interface.
- Access modes: **Carrier Sence Multiple Access (CSMA)** (starting product), **Time Division Multiple Access (TDMA)** (future products).



POINT2POINT Network topology.



POINT2MULTIPOINT Network topology.

Product evolution (1)

- **Expansion of common TCM to the layered variant** that allow application of constellations with high cardinalities: **16QAM** (two layers) **to 256QAM** (four layers). This expansion will require change of channel synchronization to precise data aided synchronizers of phase rotation and symbol timing.
- **Addition of serial turbocode** (SCCC) **and iterative decoding network** (IDN).
- **Reducing of number of transmitting subbands** to achieving of **lower PAPR and the more effective power amplification**. This reduction will require an extension of the channel synchronization by the equalizer.
- Application of **Multiple-Input Multiple-Output (MIMO) technique** with **Polynomial Singular Value Decomposition (PSVD)**. The application will allow independent data transmissions on parallel powerlines without mutual interferences.

Product evolution (2)

1. **96MCM16 TCM-QPSK CSMA (Starting product):** 96 kHz bandwidth; 16 subchannels; Trellis code 1/2 protection; Ad-hoc synchronization (Complex Costa's loop); **POINT2POINT CSMA**; Average user data bitrate **50 kBIT/s**.
2. **96MCM16 TCM-QPSK CSMA-NET, 96MCM16 SCCC-QPSK CSMA-NET:** 96 kHz bandwidth; 16 subchannels; Trellis code 1/2 or Serial Turbocode 1/2 protection; Ad-hoc synchronization (Complex Costa's loop); **POINT2MULTIPOINT CSMA**; Average user data bitrate **50 kBIT/s**.
3. **96MCM16 TCM-QAM CSMA-NET, 96MCM16 SCCC-QAM CSMA-NET:** 96 kHz bandwidth; 4 subchannels; **16QAM to 256QAM**; Layered Trellis code 1/2 or Layered Serial Turbocode 1/2 protection; Optimal synchronization (Maximum-Likelihood algorithm); **POINT2MULTIPOINT CSMA**; Average user data bitrate from **100 kBIT/s to 200 kBIT/s**.
4. **3X96MCM16 TCM-QAM TDMA-NET, 3X96MCM16 SCCC-QAM TDMA-NET:** PSVD based 3x3 MIMO; 96 kHz bandwidth; 4 subchannels; **16QAM to 256QAM**; Layered Trellis code 1/2 or Layered Serial Turbocode 1/2 protection; Optimal synchronization (Maximum-Likelihood algorithm); **POINT2MULTIPOINT TDMA** with retranslation; Average user data bitrate from **300 kBIT/s to 600 kBIT/s**.

Product comparison

	MODULATION	NUMBER OF CARRIERS	SAMPLING FREQ. [kHz]	BANDWIDTH [kHz]	MAXIMAL BITRATE [kBIT/s]	ALPHABET
OUR CONCEPT	**FDM**	**16**	**250**	**96 (27-123)**	**61.9 to 247.6 1/2 CODE PROTECTED**	**QPSK, 16QAM 64QAM, 256QAM**
G3-PLC	OFDM	36	400	56 (35–91)	33.4 CODE PROTECTED	BPSK, QPSK
PRIME	OFDM	97	250	47 (42-89)	128.6 UNCODED	BPSK, QPSK, 8PSK

Conclusion

- **Novel approach** of data transmission over medium-voltage power lines **based on FDM technique**: alternative product to PRIME standard.
- **The prototype** has been **developed and** it is **prepared for serial production**.
- **Beta version** of complete L1 firmware is going to be released to the end of 2017. **Maximum element consumption** was set at **10k** and **maximum clock frequency** is going to be increased to **150 MHz**.
- **Product evolution** directions have been **discussed**. **All scenarios** were **examined through computer simulations**.

Top level entity	LEs	REGs	Mem. bits	Multipliers	Max. clock freq. [MHz]
Transmitter	788	382	9376	3	101.34 (Model 85C)
Reciever	4054	1954	80096	16	103.06 (Model 85C)

Compilation report of L1 firmware (Alpha version) in Altera Cyclone III.

The end – Thanks for your attention