

PLM Smart Plug Solutions



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- The Smart Plug Concept
- The PLM smart plug demo board
 - Hardware:
 - PLM section
 - Metering Section
 - Firmware:
 - Architecture
 - Communication protocol
- Conclusions



Smart Grid Technology

The **Smart Grid** integrates new innovative tools and technologies from Energy *generation*, *transmission* and *distribution* all the way to consumer appliances and equipment.

transmission and distribution all the way to consumer appliances and equipment.



... the intelligent power network of the future



Home Smart Grid SCENARIO

The key players in Home Smart Grid Scenario are the following:

- ✓ In-Home Display
- ✓ E-Vehicle
- ✓ Smart Meter
- ✓ Smart Plug
- ✓ Concentrator
- ✓ Solar Panel



→ This presentation focus on **PLM SMART PLUG**



Smart Plug concept



What is a Smart Plug?

 Is an 'intelligent' plug to which you connect home appliances, white goods, lights, TV and etc., to easily monitor and control the power consumption using remote control panel

Main Features:

- Monitor Home Appliance Loads Power consumption
- Remotely Turn ON/OFF loads
- Protect Loads from over-currents
- Schedule Automatic Turn ON/OFF of the Loads
- PLM Connectivity to In-Home Display and Control Panel







ST Solution Smart PLUG



The PLM Smart Plug: Design Challenges

→ Metering Section:

- High Accuracy measurements in a wide range:
 - (class 1 AC watt meters)
 - » 1% in 1:5000 dynamic range
 - This accuracy depends on:
 - » load type (resistive, inductive, capacitive)
 - » Current sensor type (shunt, CT, Rogowski coil)
 - » Temperature (shunt resistors)
 - » Noise capture of analog tracks
 - » Ripple on Active energy
- Calibration: usually it is a very long process
- Meet Regulatory Compliances:
 - Single Phase: IEC61036 and ANSI C12.1
- Low cost



- Communication Robustness depends on:
 - Line Noise
 - Line Attenuation
 - Line Coupling
- A robust design has to:
 - Maximize the S/N ratio
 - Minimize the signal attenuation

Attenuation sources





The PLM Smart Plug demo board: overview

Intelligent Wall Plug to monitor/manage remotely energy consumption by Power Line Modem

Key Features:

- Energy consumption and electrical parameters monitoring
- Relay modes for On/Off features
- STPM01/10 energy meter IC
- Network/Standalone operative mode

Connectivity: Power Line Modem – ST7540 BFSK 4.8Kbs

Typical Applications:

- Smart Grid
- Home/building automation systems

STM32F103CBT6	32-bit MCU ARM Cortex-M3			
STPM01	Energy meter			
ST7540	B-FSK PLM			
ALTAIR05T-800	AC/DC switching regulator			
LD1117ADT33TR	3.3V linear regulator			







PLM SmartPlug: Block Diagram





The PLM Smart Plug demo-kit: overview

- » Hardware
 - » STEVAL-IHP002V2
 - PLM Smart-Plug (to create PLM Home Area Network)
 - » STEVAL-IHP003V1
 - PLM Data Concentrator connected to a PC via RS232



- » Software
 - » Demo PC-GUI to manage PLM HANs and energy consumption;
 - » Smart-Plug application;
 - » PLM protocol stack (PHY, MAC and NTW)





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The PLM Smart Plug demo-board

Hardware Description

- » The power line modem section
- » The metering section



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The PLM Smart Plug demo-board

ST7540: The Power Line Modem section





ST7540 Power Line Modem device

• FSK modulation at 4.8kbps

• MAIN FEATURES:

- Half duplex Frequency Shift Keying (FSK) transceiver;
- Integrated single ended power line driver with accessible input and output terminals and programmable voltage and current control;
- SPI/UART microcontroller interface;
- Single 7.5 to 13.5V supply voltage;
- Very low power consumption (Iq=5mA);
- 8 programmable transmission frequencies in CENELEC bands A, B and C;
- Programmable BAUD rate from 600 to 4800 bps;
- Programmable carrier or preamble detection;
- Band-in-use detection;
- Secure access 48 bit control register;
- Programmable header and frame length recognition;
- Watchdog timer;







ST7540 coupling filters





ST7540 Transmission filters





ST7540 Receiver filters

The PLM Smart Plug demo-board

Equation 4

$$R(s) = \frac{\frac{s \cdot L_{6} + R_{L}}{R_{17}L_{6}C_{26}}}{s^{2} + \frac{R_{17}R_{L}C_{26} + L_{6}}{R_{17}L_{6}C_{26}} \cdot s + \frac{R_{17} + R_{L}}{R_{17}L_{6}C_{26}}}$$

where R_L is the DC series resistance of the inductor (in our case, about 2.7 Ω). The center frequency and the quality factor of the filter can be expressed as:

Equation 5

$$fc = \frac{1}{2\pi} \bullet \omega_{C} = \frac{1}{2\pi} \sqrt{\frac{R_{17} + R_{L}}{R_{17}L_{6}C_{26}}} \cong \frac{1}{2\pi\sqrt{L_{6}C_{26}}}, \quad Q = \frac{R_{17}L_{6}C_{26}}{R_{17}R_{L}C_{26} + L_{6}} \bullet \omega_{C}$$



RX Passive Filter Response

RX Passive Filter

ST7540 Output Current/Voltage

Output Voltage level setting

V(PA_OUT) [V _{RMS}]	V(PA_OUT) [dBuV _{RMS}]	R ₇ [kΩ]	R ₈ [kΩ]		
0.500	114	0.620	1.5		
0.800	118	1.8	1.5		
1.000	120	2.7	1.5		
1.125	121	3.3	1.5		
1.250	122	3.9	1.5		
1.500	124	5.1	1.5		
2.000	126	6.2	1.5		
2.250	127	8.2	1.5		
2.500	128	9.1	1.5		
3.160	130	11	1.5		

Table 2. Output voltage level setting through V_{sense} partitioning - typical values

Power line modem section

Output Current Limit setting

Figure 2. Typical curve for output current limit vs. R_{CL} value









The PLM Smart Plug demo-board

• STPM01: The Metering section



STPM01: Metering Section

MEASUREMENT

- Active, Reactive, Apparent Energies, Vrms, Irms, Frequency
- SENSORS: Rogowski*, Current Transformer, Shunt
- OPERATION
 - Stepper Motor *
 - MCU based
- ACCURACY: 0.1% in 1:1000 range
- TAMPER PROOF: 2 current channels available
- SUPPORT IEC61036 AND ANSI C12.1
- CALIBRATION
 - Very short calibration time
 - No ripple in the active energy
 - Separated for voltage and current
- FLEXIBILITY
 - from low to high end allows re-use of already tested boards layouts
- **OTP***
 - Prevention of tamper by changing calibration data
 - No need of loading the configuration data from MCU at startup
 - Perfect data retention in harsh environment







* NOT present on STPM10

STPM01 schematic





STPM01 schematic







ST7540 PLM – Data Concentrator Node

PLM Master, Data Concentrator:

- Serial Bridge Bode: RS232 to/from PLM bridge
- PHY Layer:
 - PLM chipset: ST7540
 - FSK modulation with low frequency deviation
 - Centre frequency 132.5 kHz ± 0.2%
 - Bitrate: 4800 or 2400 bits/s
 - PLM communication compliant with EN50065-1 (band C)
- Data Link Layer, Network Layer, Application Layer:
 - Protocol Processor: STM32
- Power Management:
 - SPAC265-3W AC-DC switched-mode power supply module.
 - 85Vac to 240Vac



Key products:

ST7540; STM32F103C8T6; ST1S03PU; ST3232C.





UART/RS232 interface

STEVAL-IHP003V1

PLM Smart Plug Scenario 23



PLM Smart Plug Scenario Hyper Terminal Command



PLM SmartPlug: Firmware Overview



PLM SmartPlug: Communication Protocol Overview

Overview

- Power Line Modem Communication compliant to EN50065-1 (band C)
- **FSK**, FEC correction
- Data frame with max length of 100 bytes, CRC16, fixed ACK frame
- Network and Transport layers customized for the specific application.

General Specifaction

- Static Network plus repeater
- Node address set by serial communication
- Node repeater function set by serial communication
- MAC function with FEC



PLM SmartPlug: Firmware Architecture





PHY: Physical Level

ST7540 role:

- CENELEC 50065 band C
- FSK modulation with low frequency deviation
- Centre frequency 132.5 kHz ± 0.2% (± 0.25 kHz)
- Bit Rate 2400 bits/s.

STM32 role:

Forward Error Correction (FEC) implemented to correct phase synchronous disturbances with a duration up to 1 ms





DLL : Data Link Level

STM32 role:

- Fixed length (telegrams) messages with 100 bytes payload
- ACK and Timeout data transmission services
- CSMA/CA: Back off min (> ACK time) + random part (2 to 150ms) as explained in the previous slide. The back off algorithm is not exponential and it is recalculated each time the band is in use before the transmission.
- CRC16 protection with re-transmission mechanism





ST7540 DLL : Data Link Level



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NET : Network Level

STM32 role:

- Num.Nodes: It supports up to 65535 nodes in each network
- Address (nodes and repeaters) statically
 assigned by serial communication
- Repeaters store a static routing table





Application Layer

STM32 role:

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- Each node reads consumption data e sends it to the concentrator periodically
- Each node can receive commands to switch on/off or to dim the load





Application Layer: Example configuration



PLM SmartPlug: ST products Overview



STM32 today – platform effect ³⁶



STM32 – 7 product series ³⁷

Common core peripherals and architecture:

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chilecture.		168 MHz	lln to	lle to				SDIO		Crypto/			
ommunication peripherals: JSART, SPI, I²C		Cortex-M4 with DSP and FPU	UP to 192-Kbyte SRAM	0p to 1-Mbyte Flash	2x USB 2.0 OTG FS/HS	3-phase MC timer	2x CAN 2.0B	2x I ² S audio Camera IF	Ethernet IEEE 1588	hash processor and RNG	STM32 F4		
lultiple general-		STM32 F3 s	series - Mix	ked-signal v	with DSP (ST	M32F302/303	3/313/372/	373/383)					
ourpose timers egrated reset and own-out warning		72 MHz Cortex-M4 with DSP and FPU	Up to 48-Kbyte SRAM & CCM-SBAM	Up to 256-Kbyte Flash	USB 2.0 FS	2x 3-phase MC timer (144 MHz)	CAN 2.0B	Up to 7x comparator	3x 16-bit ∑∆ ADC	4x PGA	STM32 F3		
Multiple DMA	STM32 F2 series - High performance (STM32F205/215/207/217)												
2x watchdogs Real-time clock		120 MHz Cortex-M3	Up to 128-Kbvte	Up to 1-Mbvte	2x USB 2.0 OTG	3-phase	2x CAN	SDIO 2x I ² S	Ethernet	Crypto/ hash	T 3		
egrated regulator and clock circuit		CPU	SRAM	Flash	FS/HS	MC timer	2.0B	audio Camera IF	IEEE 1588	and RNG	STM32 F2		
cternal memory		STM32 F1 s	series - Ma	instream -	5 product lin	es (STM32F1	00/101/10	2/103 and 10	05/107)				
iterface (FSMC)	_	Up to	lin to	Up to	-		Un to	000					
to 3x 12-bit DAC	+	72 MHz	96-Kbyte	1-Mbyte	USB 2.0	3-phase	2x CAN	2x I ² S	Ethernet				
to 4x 12-bit ADC		Cortex-M3 CPU	SRAM	Flash	016 FS	MC timer	2.0B	audio	IEEE 1588	STM32 F1			
· · · · · · ·		STM32 F0 s	series – En	try level (S1	FM32F050/0	51)							
2 kHz oscillator		48 MHz Cortox-M0	Up to	Up to	3-phase	Comparator	CEC						
ow-speed and h-speed internal BC oscillators		CPU	SRAM	Flash	MC timer	συπραιατοι	0EC	STM32 F0					
$0 \text{ to } \pm 85 ^{\circ}\text{C}$ and		STM32 L1 series - Ultra-low-power (STM32L151/152/162)											
up to 105 °C operating mperature range		32 MHz Cortex-M3 CPU	Up to 48-Kbyte SRAM	Up to 384-Kbyte Flash	USB FS device	Up to 12-Kbyte EEPROM	LCD 8x40 4x44	Comparator	BOR MSI VScal	AES 128-bit	STM32 L1		
Low voltage		STM32 W s	eries - Wir	eless (STM:	32W108)								
1.65/1.7 to 3.6 V bending on series) nperature sensor		24 MHz Cortex-M3 CPU	Up to 16-Kbyte SRAM	Up to 256-Kbyte Flash	2.4 GHz IEEE 802.15.4 Transceiver	Lower MAC Digital baseband	AES 128-bit	STM32 W					

STM32 F4 series - High performance with DSP (STM32F405/415/407/417)

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STM32F/L/W Complete offer 38



ST PLC product roadmap



ST7540 power line modem

MAIN FEATURES:

- Half duplex Frequency Shift Keying (FSK) transceiver;
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- Band-in-use detection:
- Secure access 48 bit control register;
- Programmable header and frame length recognition;
- Watchdog timer:







STarGIRD[™] SoC: The narrowband PLC platform ready now for massive industrial smart grid roll outs



Metering Products Portfolio 42



Energy monitoring: STPM01

Complete set of electrical parameters available through SPI interface (Vrms, Irms, frequency, active, reactive and apparent energy, status flags,...);

MAIN FEATURES:

- LED driving for visible information about power, tamper detection and no-load conditions;
- Zero-cross sine wave current signal available, allow turn on/off of heavy inductive loads avoiding arcing phenomenon;
- OTP for calibration and configuration with very fast and accurate software calibration;
- Support 50-60HZ IEC62052-11, IEC62053 2x specification;
- Less than 0.1% error;





The PLM E-Meter

• STPMS2 Smart sensor:

- Vcc supply range 3 5.5V
- 2nd order Sigma Delta Modulators
- Programmable chopper stabilized low noise and low offset amplifier
- Exceed 50-60 Hz IEC 687/1036 spec for class1, class0.5 and class0.2 AC watt meters
- Less than 0.1% error over 1:5000 range
- Internal low drop regulator @ 3V typ
- Precision voltage reference: 1.23V and 30 ppm/ C Max (only STPMS2L)





» STPMC1 calculator:

- » Processing of Sigma Delta current/voltage signals delivered by Smart Sensors.
- » Basic computational functions plus integrators, decimators, filters.
- » Measurement of active, reactive, apparent energy, current/voltage RMS and frequency values



The PLM E-Meter

• Metering Section: Poly-phase Proposed Solution: STPMC+STPMS2





Thank You



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