Smart Grid: Flexible PLC Solution using C2000
PLC Fundamentals
PLC definition

- Power line communication
  - Wired technology
  - Use of the electricity networks for data transmission
  - No expensive deployment

PLC Communication depends on

- The modulation
- The frequency band
- The protocol

Modulation on the main
Power Line Communications is a *rapidly emerging technology*


Flexible PLC implementation is key

Multiple Applications for PLC Narrowband

Various modulation schemes
- FSK
- S-FSK
- OFDM

Multiple standards
- IEC 61334
- Prime
- G3
- Incoming ones

Local regulations
- CENELEC
- FCC
- ARIB
PLC Frequency Bands (Europe) and Frequency regulations

Narrowband Low Frequency PLC (0-500kHz)

- Cenelec A: exclusively for energy provider
- Cenelec B, C, D: open for other end-applications
- Cenelec A, B, D: protocol layer defined by standards or proprietarily defined
- Cenelec C regulated – CSMA access

- USA: FCC band (10...490kHz)
- Japan: ARIB band (10...450kHz)
- China: 3-500kHz band (EPRI prefers 3...90kHz)
Modulation Technologies

FSK

OFDM

S-FSK

OFDM

Texas INSTRUMENTS
PLC is a Robust Means of Communicating Over Power Lines

Applications
✓ E-Metering
✓ Lighting
✓ Home Automation
✓ Industrial
✓ Solar
✓ EVSE (Electric Vehicle charging)

Technologies (modulation schemes)
✓ FSK
✓ S-FSK
✓ OFDM

Standards
✓ Prime
✓ G3
✓ IEC 61334

Regulations
✓ CENELEC
✓ FCC
✓ ARIB

TI is the only solution provider that can address all of these technologies and standards with a common HW configuration!
## PLC PHY Standards Compliance

<table>
<thead>
<tr>
<th>Standard</th>
<th>Technology</th>
<th>Band occupied</th>
<th>Data rate range</th>
<th>Target TI processor</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>SFSK</td>
<td>60–76 KHz</td>
<td>1.2–2.4 kbps</td>
<td>F28027</td>
</tr>
<tr>
<td>PRIME</td>
<td>OFDM</td>
<td>42–90 kHz</td>
<td>21–128 kbps</td>
<td>F28069/ F28PLC83</td>
</tr>
<tr>
<td>ERDF G3</td>
<td>OFDM</td>
<td>35–90 kHz</td>
<td>5.6–45 kbps (6-72kbps)*</td>
<td>F28069/ F28PLC83</td>
</tr>
<tr>
<td>P1901.2/ G3 FCC</td>
<td>OFDM</td>
<td>35–450 kHz</td>
<td>34-234 Kbps (37-580kbps)*</td>
<td>F28M35x</td>
</tr>
<tr>
<td>PLCLite (TI Proprietary)</td>
<td>OFDM</td>
<td>42–90 kHz</td>
<td>2.4–21kbps</td>
<td>F28035/ F28027</td>
</tr>
<tr>
<td>FlexOFDM (TI Proprietary)</td>
<td>OFDM</td>
<td>Sub 10kHz to FCC</td>
<td>2.4–128kbps</td>
<td>F28069/ F28M35x</td>
</tr>
</tbody>
</table>

* Without overhead
# TI Power Line Communication Benefits

## Flexible, scalable and easy to customize

### Flexibility via Software

Free TI PLC library plcSUITE™ adapts to evolving standards, enables quick differentiation and customization by easily separating modulation and networking protocol, offers design simplicity and field upgradability.

| Single Hardware | can support multiple modulation and standards |

### Hardware Flexibility (AFE + MCU)

Integrated AFE reduces design cycle and risk while reducing number of components and optimizing system cost. Multiple operating modes allows for power savings and optimization. Thermally enhanced exposed pad package ensures excellent thermal performance and reliability. Greater flexibility in system cost optimization with AFE and digital portion roadmap.

| Greater Reliability and System Cost Optimization |

### Expertise and Support

WW PLC R&D Center in Dallas, analog and digital expertise, field test experience, active participation in standards bodies ensures leading edge solution delivery.

| Reduces development time |
PLC Hardware
TI PLC Solution – Fully Programmable & Scalable

- Dual chip solution based on optimized C2000 + Analog Front-End
- Fully programmable solution on single F28x (MAC & PHY)
- Support S-FSK – and Low Frequency Narrowband OFDM (LF NB OFDM) (PRIME – G3)
TMS320F28x™ 32-Bit MCU Family Key Benefits for PLC

**Flexibility via SW**
- Software compatibility across all F280xx
  - Easy migration across device family
  - Leverage investments
- Upgradability via software
- Multi-protocol support (S-FSK/PRIME/G3)

**Performance for computation optimization**
- VCU engine (Viterbi, complex math and CRC)
  - OFDM reduced power consumption
- SW Encryption and memory protection for data security
- Dedicated HW accelerators

**Integration**
- 12-bit ratio-metric ADC with individual channel triggers
  - More accurate resolution – limit drift errors
- 3 analog comparators with 10-bit reference
  - Zero crossing detection/synchronization
- Dual on-chip oscillators
  - Intelligent clocking system monitoring
- On-chip Flash up to 256kB
- On-chip serial ports for flexible interfacing

**Cost optimization**
- Single 3.3V supply available in the family
  - Cost and board space saving
  - Save 1.8-V power and SVS
- Multiple package options down to 32-pin
  - Board space saving

---

**Piccolo**

- **C28x 32-bit 80MHz**
- **VCU Unit**
- **CLA**
- **DMA-6CH**

**Memory**
- 256 KB Flash
- 100 KB RAM
- Boot ROM
- **Real-Time JTAG**

**Power & Clocking**
- Dual Osc 10 MHz
- On-Chip Osc
- Dynamic PLL Ratio Changes
- POR
- BOR

**Peripherals**
- 3x Comparator
- Missing Clock Detection Circuitry
- 128-Bit Security Key/Lock

**Converter**
- 16 ch, 2SH, 12-bit, 3 MSPS ADC

**Serial Interfaces**
- 2x SPI, 1x McBSP
- 2x SCI
- 1x I²C
- 1x CAN

**Timer Modules**
- 8x ePWM Modules:
  - 16x PWM outputs: (8x 150ps high-res)
- 3 x 32-bit eCAP
- 4 x HRCAP
- 2 x 32-bit eQEP
- Watchdog Timer
- 3x 32-bit CPU Timers

**105C/125C and Q100**

F28069 Piccolo device block diagram example
VCCP Module (Viterbi, CRC and Complex arithmetic co-Processor)

**CRC Unit (CU)**
- Supports generation of CRC8, CRC16 and CRC32 on data stored in memory
  - Byte-wise calculation to support PRIME

**Viterbi Unit (VU)**
- Supports efficient SW implementation of Viterbi decoder by performing the ADD-Compare-Select and traceback operation in hardware
  - 1 cycle branch metrics initialization for CR=1/2 and 2 cycle branch metrics initialization for CR=1/3
  - 2-cycle Viterbi butterfly operation (Viterbi Butterfly SW on F2812 takes 15 cycles)
  - 3-cycle Viterbi traceback operation per Viterbi stage (Traceback SW on F2812 takes 15 cycles)

**Arithmetic Unit (AU)**
- Supports complex number arithmetic and FFT calculation
  - 2 cycle complex-number multiplication with 16-bit x16-bit = 32-bit real and imaginary parts
  - 1 cycle complex-number addition
  - 2-cycle Complex multiply-and-accumulate (MAC)
  - A repeat Complex-MAC operation
  - Instruction to support 5-cycle 16-bit FFT butterfly
Stellaris® Cortex™-M3 + PLC Modem Integrated
F28M35x – First series in Concerto™

PLC modem subsystem
- 32-bit C28x™ programmable PLC engine
  - SFSK, PRIME, G3
  - OFDM support up to FCC band
  - Up to 512kB flash
  - Code security
  - 1 UART
  - 1 McBSP

Application
- 32-bit ARM® Cortex-M3
  - Scalable up to 100MHz
  - Up to 512kB Flash
  - Code security
  - 4 synchronous serial interfaces SSI
  - 5 UART
  - 2 I²C
  - AES128 & 256 encryption (ROM tables)

Sample Availability 2Q11

128 QFP 0.4 mm, 144 QFP 0.5 mm
105°C/125°C and Q100
Highest Level of Integration and Performance while Maintaining Flexibility

QFN-48 (7 x 7 mm)

AFE031 (replaces discrete) INCLUDES PA

Large thermal pad

LINE COUPLING CIRCUIT

DISCRETE ANALOG FRONT END
**AFE030**

**Low Cost Fully Integrated PLC Analog Front End**

**Features**
- Highly integrated
  - Integrated programmable TX and RX filters & PGA
  - Two integrated zero-crossing detectors
  - Two-wire transmitter and receiver op-amps
- Highly linear, large output swing power amplifier: 9Vpp @ 1A (12V supply)
- Integrated protection functions
  - Output enable/disable control
  - Thermal and over-current interrupt
  - Internal thermal overload protection
  - Resistor programmable current limit
- Direct digital SPI compliant interface
- Versatile supply, temp. range and package
  - PA Supply: (7V-24V), AV_DD supply (3.3V)
  - Extended -40°C to +125°C temp range
  - Package: 48-pin QFN with Power-Pad

**Applications**
- E-meters, solar power, HVAC and home automation
- Electric vehicles
- Street lighting
- Industrial communications

**Benefits**
- Flexible and complete AFE solution for PLC
  - Meets and exceeds Cenelec A, B, C and D band requirements as well as PRIME and G3 requirements
  - Enables broadcast of signals using FSK, S-FSK modulation schemes
- Enables end equipment that conforms to EN50065-1
- Improves system reliability and enables design flexibility
- Provides a complete PLC solution in conjunction with TI’s extensive MCU portfolio
- Compared to alternative solutions, provides 95% PCB area savings and greater than 10x reduction in power consumption during Rx mode while operating throughout the entire industrial temperature range
AFE031

Fully Integrated PLC analog front end

**Features**

- Highly integrated
  - Integrated programmable TX and RX filters & PGA
  - Two integrated zero-crossing detectors
  - Two-wire transmitter and receiver op-amps
- Highly linear, large output swing power amplifier: 9Vpp @ 1.5A (12V supply)
- Integrated protection functions
  - Output enable/disable control
  - Thermal and over-current interrupt
  - Internal thermal overload protection
  - Resistor programmable current limit
- Direct digital interface (glue less to TI PLC processor)
- Versatile supply, temp. range and package
  - PA Supply: (7V-24V), AV_{DD} supply (3.3V)
  - Extended –40°C to +125°C temp range
  - Package: 48-pin QFN with Power-Pad

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**Applications**

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- Street lighting
- Industrial communications
Industry’s Most Flexible, Lowest System Cost and Lowest Power PLC by Design

• **FLEXIBILITY**
  – Common AFE footprint allows for CENELEC, FCC, ARIB, PRIME, G3, FSK, SFSK solution – no other competitor can claim this – allows customers to **serve many WW markets with single solution defined by SW**

• **LOWEST SYSTEM COST**
  – TI’s PLC solution includes the complete PA – **compare to competitors that require build your own PA** from large, expensive discrete power transistors
  – Increasing levels of integration removes more and more passive components

• **LOWEST SYSTEM POWER**
  – On chip signal detection allows MCU to be placed in lowest possible power mode, waking up only upon interrupt for power sensitive applications like solar j-box or lighting **~10mW in standby mode**
TI PLC Modem Development Kit (TMDSPLCKIT-V3)

**TI PLC DK contains:**
- 2 PLC modems
- Power supply and cables
- GUI and documentations
- Run any IP applications through PC host
- **Part#:** TMDSPLCKIT-V3
- **Price:** $599 USD
- Distribution and TI eStore
- **plcSUITE™ Software** available via download

- Robust narrowband PLC modem over low-voltage/medium-voltage power line
- PLC standards/modulation supported
  - PRIME
  - G3
  - FlexOFDM™
- Optional FCC band discrete AFE available
- Compatible with optional Piccolo and Concerto Control Cards

- Software reference design package: **plcSUITE** APIs, Libs. Source available pending NDA
- AFE operating frequency range in CENELEC A, and BCD bands
- Easy integration into end-point or network devices of AMR/AMI systems
- **NRE and royalties FREE**
PLC Kit V3 Docking Station Overview

- DB9/ RS232 Serial Port (SCI)
- SCI x2
- SPI
- I²C
- CAN
- SCI
- JTAG
- USB
- JTAG Emulation / USB Serial (SCI)
- Power Supply
- 3.3 V
- 5V
- V_{DD}
- L/N
- AFE Module
- PWM
- SPI
- ADC
- ECAP
- Coupling Circuit
- Optional AC/DC Power Supply
- 85-280 VAC
- 5V
- 3.3 V
TI System on Module (SoM)

- TI SoM are design suggestions for a more optimized PLC system that can be plugged into an existing application: these are not production proof designs
- TI provides schematics, gerber and layout and can also provide samples
- Feature the F2806x + AFE031 combination
- PiccoloA and PiccoloB SOM versions in development
- Support PRIME/G3/FlexOFDM and S-FSK in 4Q
- Available on request: smartgrid@ti.com
# TI PLC Product Portfolio

<table>
<thead>
<tr>
<th>Portfolio/Features</th>
<th>F28PLC35/AFE030 (PLC-Lite)</th>
<th>F28PLC83/AFE031 (CEN-A/BCD)</th>
<th>F28M35/AFE032 (FCC)</th>
<th>F28PLC7x/AFE032/CC1260 (PLC+RF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standards/Technologies</td>
<td>FlexOFDM</td>
<td>PRIME/G3/G1/FlexOFDM</td>
<td>P1901.2/G3-FCC</td>
<td>P1901.2/802.15.4g</td>
</tr>
<tr>
<td>Max Bit Rate (PHY)</td>
<td>TI: 21Kbps</td>
<td>TI: 64-128Kbps</td>
<td>200Kbps</td>
<td>400-500Kbps</td>
</tr>
<tr>
<td>Other: 2.4-28Kbps</td>
<td>Other: Same</td>
<td>Other: Same</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency Bands supported</td>
<td>CELENEC A, CENELEC BCD half band</td>
<td>CENELEC A, B, C, D With Tone Masks</td>
<td>CENELEC A,B,C,D FCC*, ARIB*</td>
<td>CEN A,B, C, D FCC, ARIB</td>
</tr>
<tr>
<td>MCU+AFE Cost</td>
<td>Lowest</td>
<td>Low</td>
<td>Low-Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Maximum CPU Clock Rate</td>
<td>60MHz</td>
<td>90MHz (VCU-I)</td>
<td>150MHz (VCU-I)</td>
<td>150MHz (VCU-II)</td>
</tr>
<tr>
<td>IC and Kit Availability</td>
<td>Now</td>
<td>Now</td>
<td>Now (*4Q12)</td>
<td>Q2/2013</td>
</tr>
<tr>
<td>TI Product Advantages</td>
<td>• low cost with OFDM robustness</td>
<td>• Multiple standards</td>
<td>• Industry 1st PLC and SDR integrated solution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• FlexOFDM with flexible band selection</td>
<td>• Certified SW and field proven</td>
<td>• highest performance for NB-OFDM</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Ultra-good NBI performance</td>
<td>• Better receiver algorithm</td>
<td>• Additional robust features: Coherent, etc</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• CLA for applications</td>
<td>• Better network formation algorithm</td>
<td>• Adaptive Tone Mask</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• CSMA/CA MAC</td>
<td>• Simple user interface</td>
<td>• Field proven</td>
<td></td>
</tr>
<tr>
<td>Target Applications</td>
<td>• In-Home-Display to eMeter</td>
<td>• AMR/AMI</td>
<td>• AMR/AMI</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• eMeter to Collector</td>
<td>• IHD/HAN</td>
<td>• EV/EVSE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Solar inverter connectivity</td>
<td>• Energy Gateway</td>
<td>• IHD/HAN</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Home Area Network</td>
<td></td>
<td>• Energy Gateway</td>
<td></td>
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</tr>
</tbody>
</table>

**TI PLC EVM Kit**

**TI PLC SOM**

**3rd Party PLC Plug-in**

**Data Concentrator EVM**
PLC Software
Single HW – Multiple Standards
plcSUITE™ Software Framework

Host IF HW Driver: UART/USB
Host Control Transport Messaging Protocol
SLIP: Serial Link IP
AppEmu Embedded (Optional, used for host-less operation)

Host App SW reference

plcSUITE:
- Open source
- Layered API
- Component-wise Certifiable
- Scalable
- Lego architecture
- Custom build
- Documentation
## What Customer Wants #1: Time to Market

<table>
<thead>
<tr>
<th>Facts</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>plcSUITE™</strong> has been certified by compliance test lab</td>
<td>Customers pass meter certification in weeks</td>
</tr>
<tr>
<td><strong>plcSUITE™</strong> offers comprehensive functions: ADP, MAC, PHY with simple APIs to assist system integration</td>
<td><strong>plcSUITE</strong> has simple APIs (~12 message for G3, ~20 messages for PRIME). Customer ~1 week integration record.</td>
</tr>
<tr>
<td><strong>plcSUITE™</strong> includes both Service Node (SN) and Data Concentrator (DC) side for an “end-2-end” solution</td>
<td>Customer is able to provide “end-2-end” network level test with 50-100s node in &lt; 2 months</td>
</tr>
<tr>
<td><strong>plcSUITE™</strong> went through WW field tests for PHY layer robustness and Network Layer with extra-ordinary performance</td>
<td><strong>plcSUITE</strong> contains many top-notch algorithms in both PHY and MAC layer to achieve top performances (details can be provided)</td>
</tr>
</tbody>
</table>

### Diagrams
- **High Level Integration**
- **End-2-End Network Solution**
- **WW Field test Certification**
- **Numerous IPs**
What Customer Wants #2: Easy to Use

Zero-Config GUI

Intermediate GUI

Wireshark Sniffer

Channel Analyzer

Automated Network Tester

HCT Message APIs
Enable Customers - Test

- Zero Config GUI
  - Point to point Connection Test
  - Plug and play
  - PHY packets transfer and statistics
  - Message transfer
  - File transfer

- Intermediate GUI
  - System configurations
  - PHY performance evaluations
  - PHY/MAC PIB set/get
  - Firmware flash

- Host application emulation
  - Network join
  - Meter readings emulation
  - Mini-DC mode for G3
What makes TI Solution Differentiate?

- Fully Programmable & Scalable

C2000/Concerto

PRIME

G3

- Enhanced Algorithms inside

<table>
<thead>
<tr>
<th>PRIME</th>
<th>G3/ G3 FCC/P1901.2</th>
<th>FlexOFDM</th>
<th>PLC-Lite</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Beacon search algorithm</td>
<td>- Enhanced CSMA/CA</td>
<td>- Adaptive sub-band Selection (up to FCC)</td>
<td>- NBI cancellation algorithm</td>
</tr>
<tr>
<td>- Adaptive ARQ timeout</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Prioritized Queuing</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- “Easy-to-use” GUI Tool
Message Flow Overview (G3/PRIME)

- Host
- PLC Modem
- System Initialization
- Network Configuration
- Data Transfer
Zero-Configuration GUI

- Automatic Port Configuration
- Easy to Demo (one-click to run)
- Zero-Configuration/Intermediate Mode
- File Transfer/Message Transfer/PHY Test Mode
Intermediate GUI

• Graphical Display for RSSI, SNR, BER, and PER
• More options for PHY Test mode
  (modulation/coding rate/power level/gain)
## TI PLC Platform and Availability

<table>
<thead>
<tr>
<th>Standards/Platform</th>
<th>F28027 (Piccolo-A)</th>
<th>F28035 (Piccolo-B)</th>
<th>F28069 (Octave)</th>
<th>F28M35 (Concerto)</th>
<th>AM180x/L138 +F28069(Octave)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 61334-5-1 PHY, MAC (S-FSK)</td>
<td>Now</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>PRIME PHY, MAC, CS</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>3Q12</td>
<td>PRIME DC baseline</td>
</tr>
<tr>
<td>IEC 61334-4-32 LLC</td>
<td></td>
<td></td>
<td>Now (v6.0.0.13)</td>
<td>Now (v5.0.0.0)</td>
<td>(v3.0.0.0) Now</td>
</tr>
<tr>
<td>G3 (OFDM)</td>
<td>N/A</td>
<td>N/A</td>
<td>Now (v5.0.0.0)</td>
<td>Now (v5.0.0.0)</td>
<td>G3 DC baseline</td>
</tr>
<tr>
<td>P1901.2 (OFDM)</td>
<td></td>
<td></td>
<td>N/A</td>
<td>1Q12</td>
<td>N/A</td>
</tr>
<tr>
<td>FlexOFDM (Proprietary flexible OFDM implementation)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>1Q12</td>
<td>N/A</td>
</tr>
<tr>
<td>PLC Lite (light version of FlexOFDM, MAC/PHY)</td>
<td>1Q 12</td>
<td>Now (v3.0.0.0)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>MCU + AFE Cost</td>
<td>Lowest</td>
<td>Low</td>
<td>Low-Medium</td>
<td>Medium</td>
<td>Medium-High</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FCC, ARIIB</td>
<td>FCC, ARIIB</td>
</tr>
<tr>
<td>Max Bit Rate (PHY)</td>
<td>2.4kbps</td>
<td>22kbps</td>
<td>200kbps</td>
<td>500kbps</td>
<td></td>
</tr>
</tbody>
</table>

- * royalties involved on the SFSK SW running on the F28027
- **FlexOFDM** is a proprietary approach taking the best of PRIME and G3 and giving flexibility of the protocol stack to customer (Customer can just pick the PHY) with focus on band agility, robustness, flexible upper layer stack, smaller MIPS/memory footprint (example: lighting, solar..)
- **Cheapest PLC only solution**: PLCLite on Piccolo A F28027
Conclusion
Conclusion

• SW Flexible Solution
  – One single HW to support S-FSK/PRIME/G3 (OFDM)
  – Flexibility at no cost adder

• TI is a strong supporter of Low Frequency Narrowband OFDM (LF NB OFDM) solution
  – PRIME/G3/FlexOFDM/PLC-Lite/G1 available today

• We are providing
  – H/W platform and schematics
  – S/W library and GUI tool
  – API Documents and User Guide
  – Project Examples (Host Application, PHY/LLC/ADP example projects)