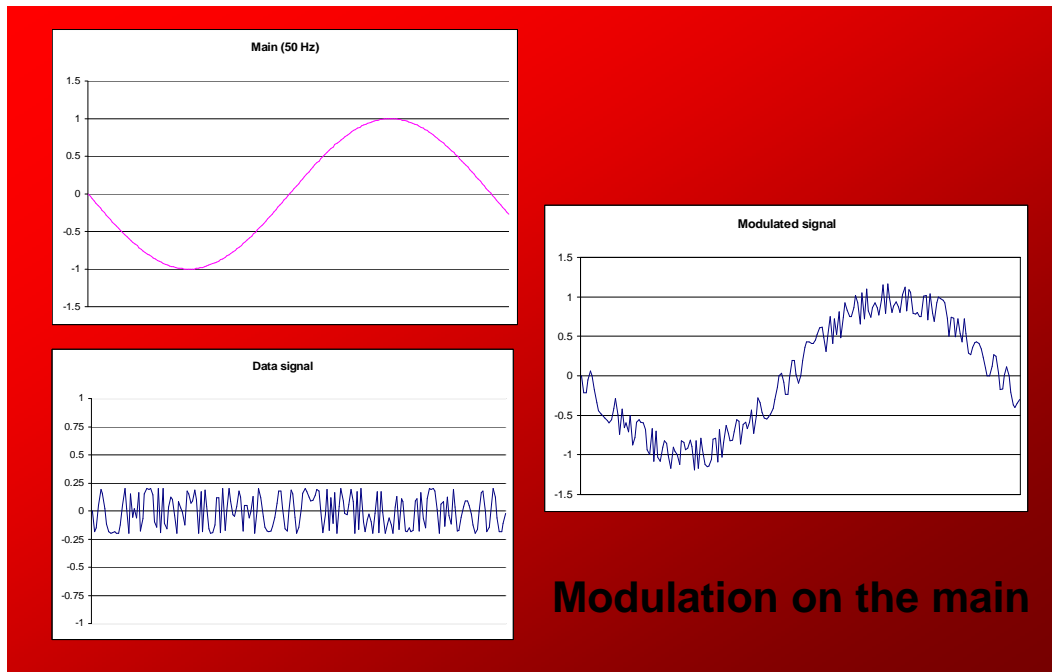


# Smart Grid: Flexible PLC Solution using C2000

# PLC Fundamentals

# PLC definition

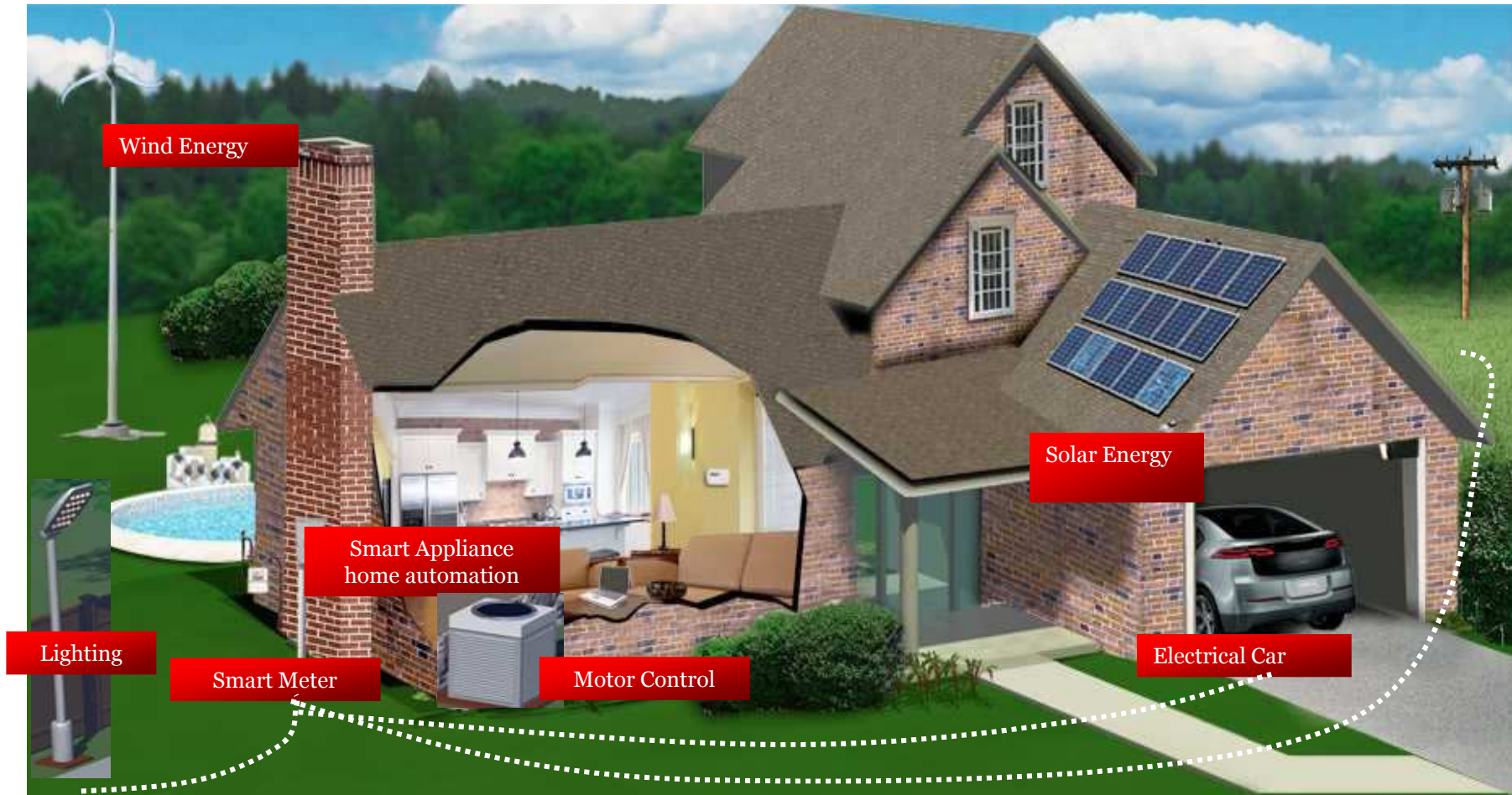
- Power line communication
  - Wired technology
  - Use of the electricity networks for data transmission
  - No expensive deployment



PLC Communication depends on

- The modulation
- The frequency band
- The protocol

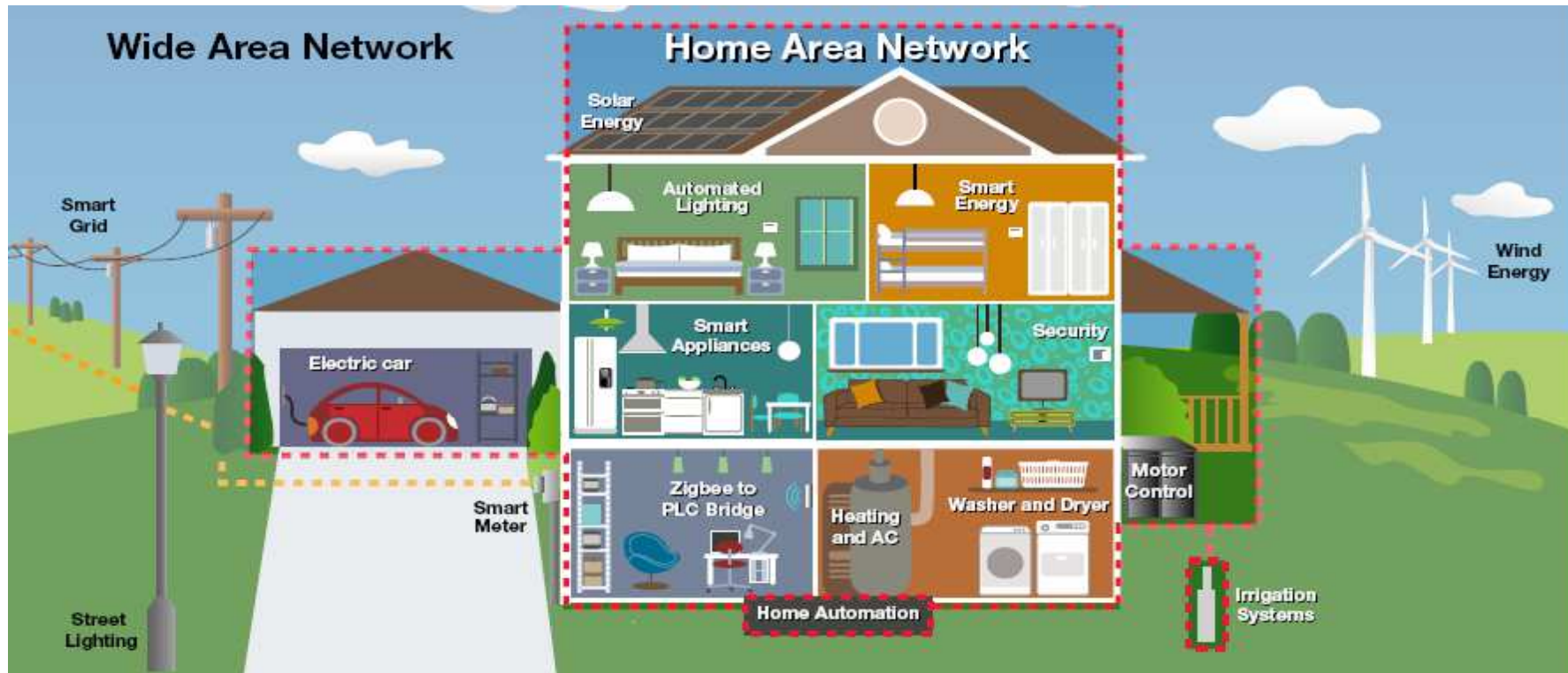
# Overview



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

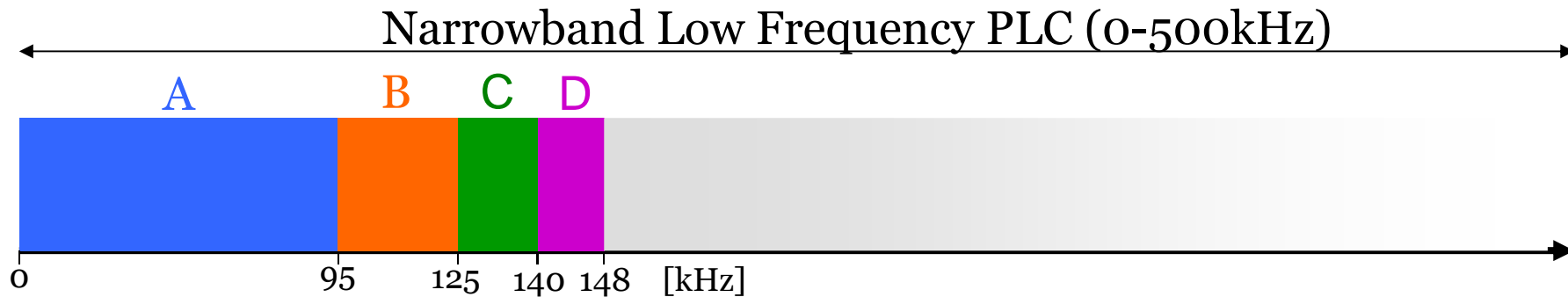
### Multiple standards

- IEC 61334
- Prime
- G3
- Incoming ones

### Local regulations

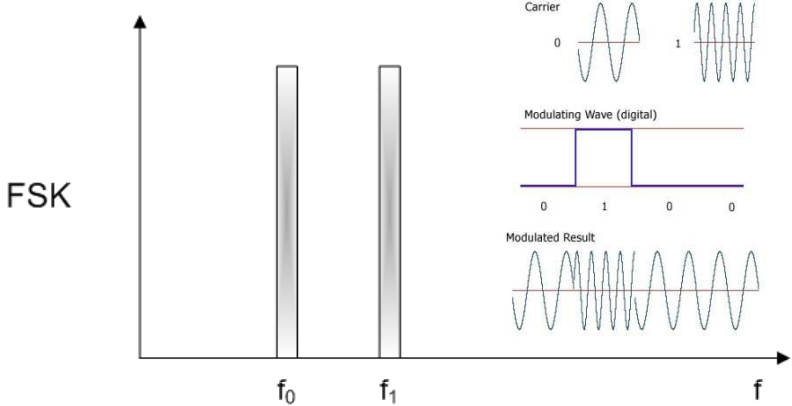
- CENELEC
- FCC
- ARIB

# PLC Frequency Bands (Europe) and Frequency regulations

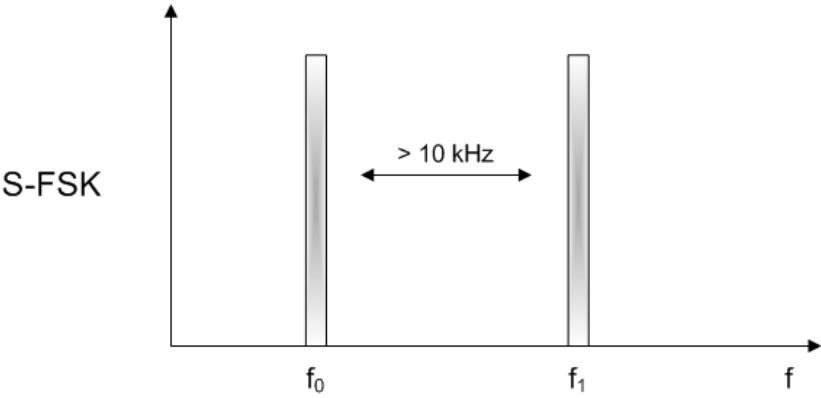
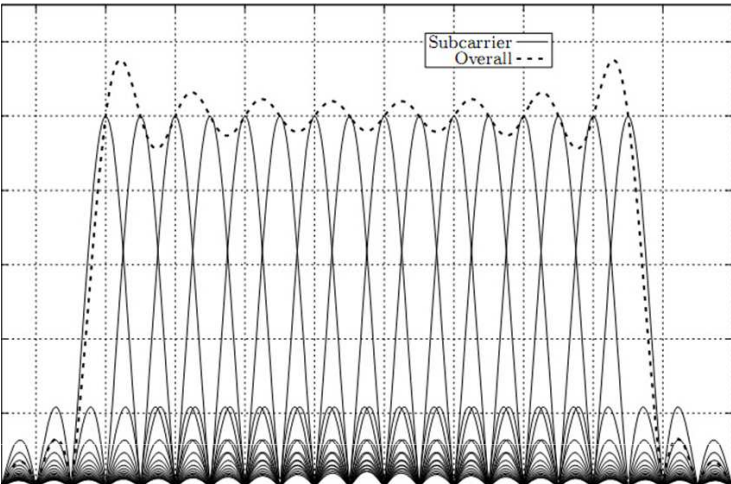


- Cenelec **A**: **exclusively for energy provider**
  - Cenelec **B, C, D**: **open for other end-applications**
  - Cenelec **A, B, D**: protocol layer defined by standards or proprietarily defined
  - Cenelec **C** regulated – CSMA access
- 
- USA: FCC band (10...490kHz)
  - Japan: ARIB band (10...450kHz)
  - China: 3-500kHz band (EPRI prefers 3...90kHz)

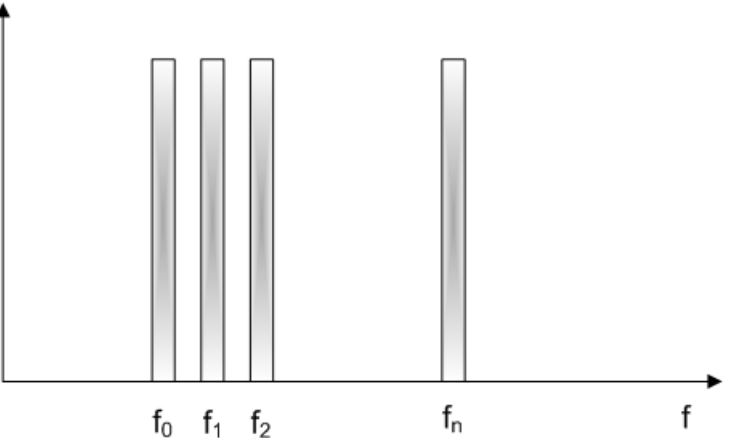
# Modulation Technologies



OFDM



OFDM



# 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

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

\* 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

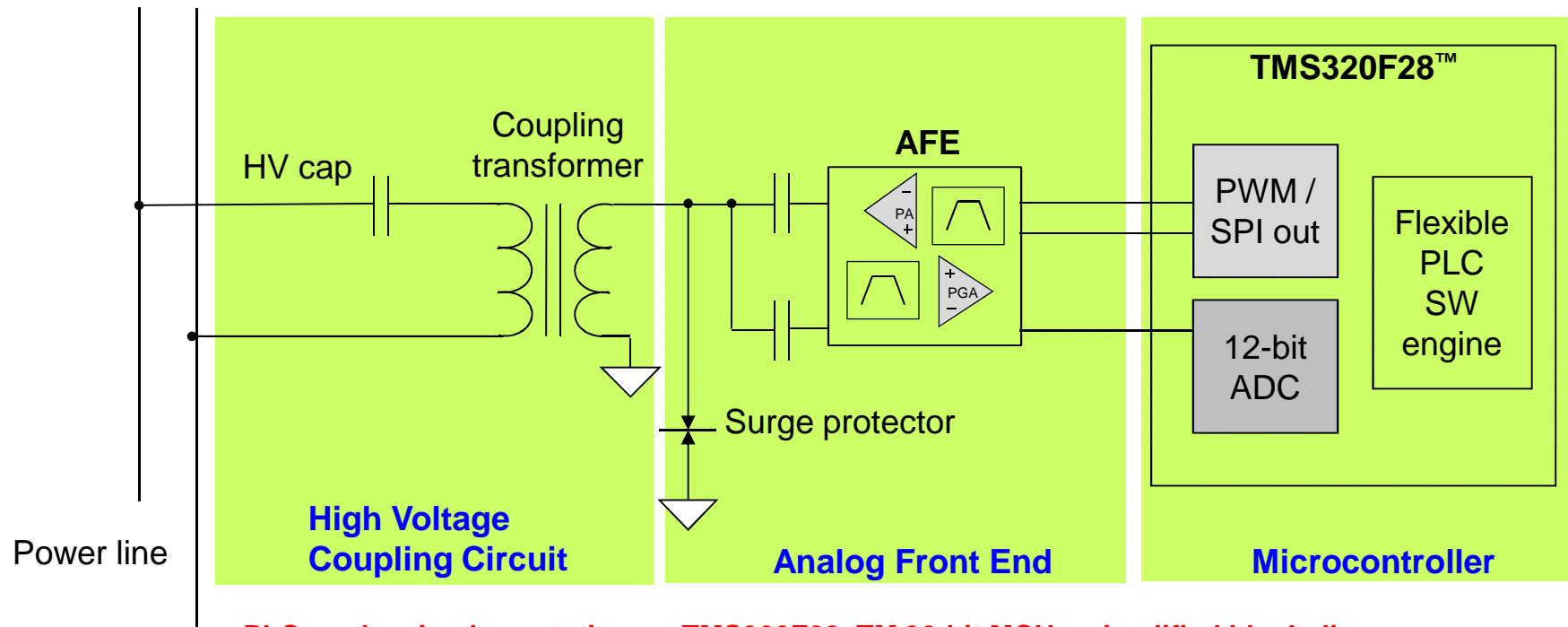
WW PLC R&D Center in Dallas, analog and digital expertise, field test experience, active participation in standards bodies ensures leading edge solution delivery.

Reduces development time

10

# PLC Hardware

# TI PLC Solution – Fully Programmable & Scalable



PLC modem implementation on TMS320F28x™ 32-bit MCU – simplified block diagram

- 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

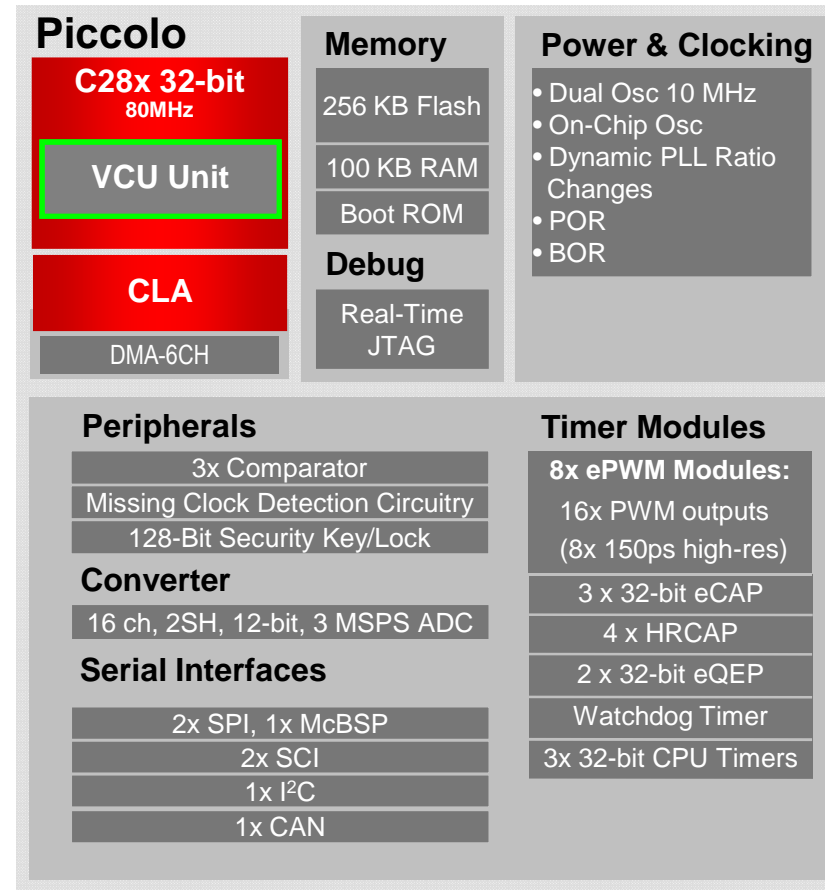
- VCU engine (Viterbi, complex math and CRC)
  - OFDM reduced power consumption
- SW Encryption and memory protection for data security
- Dedicated HW accelerators

## 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

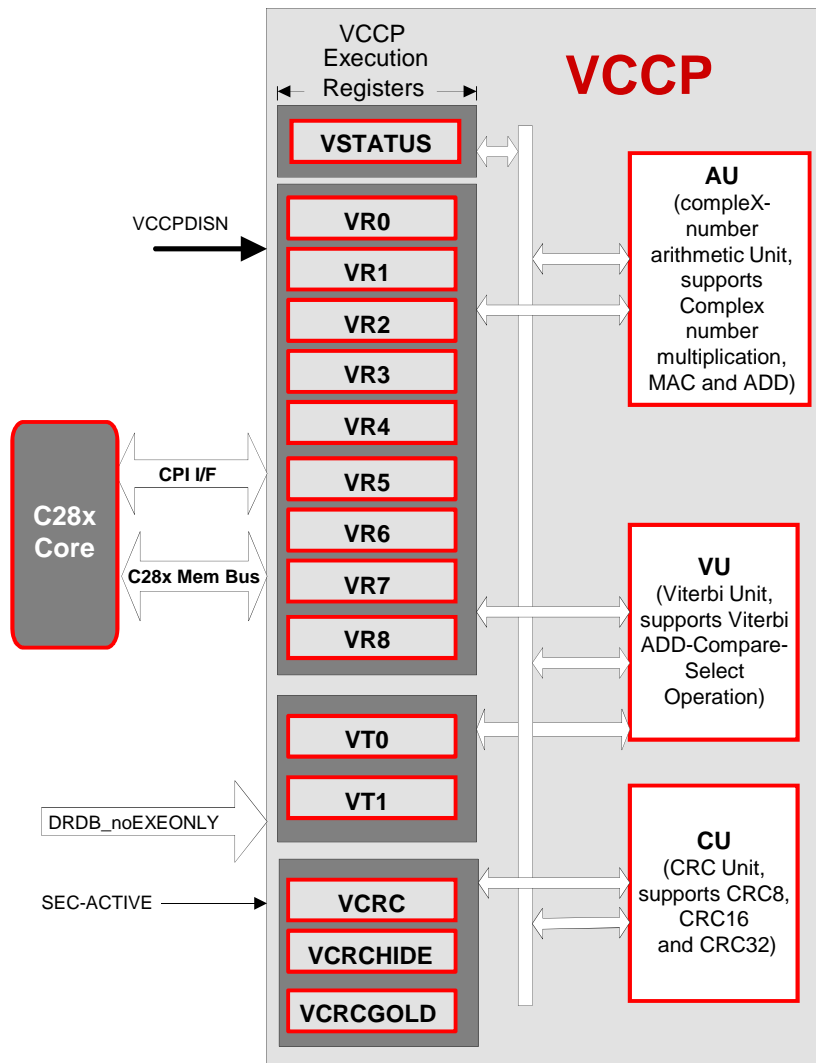
## Cost optimization

- 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



**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 trace back 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<sup>®</sup> Cortex<sup>™</sup>-M3 + PLC Modem Integrated

## F28M35x – First series in Concerto<sup>™</sup>

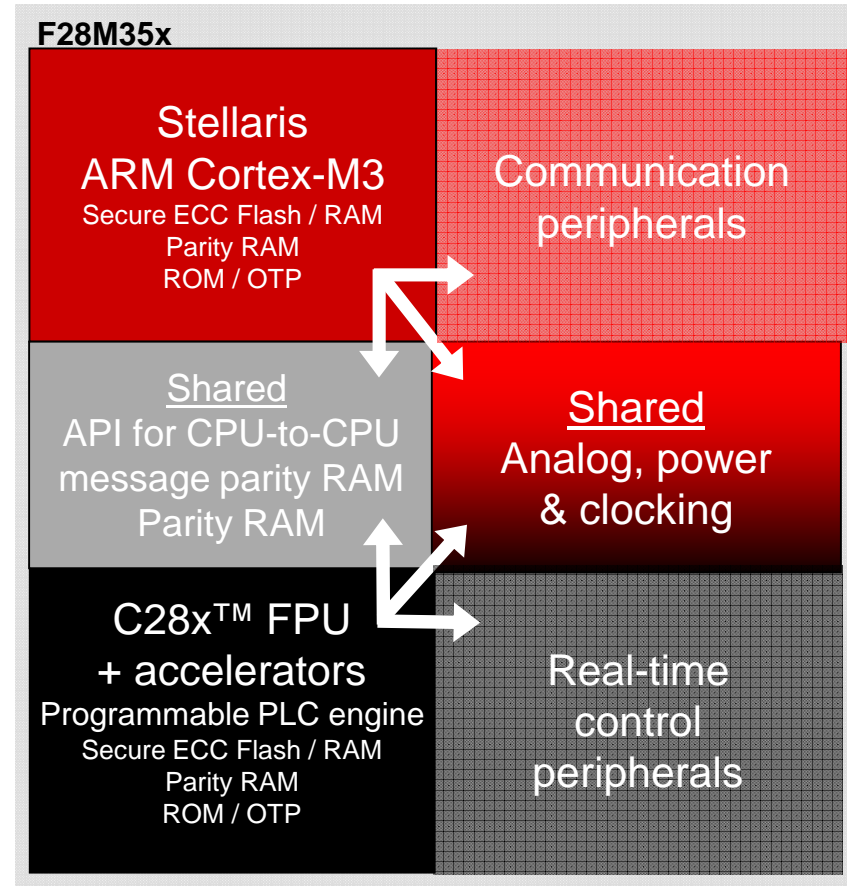
### PLC modem subsystem

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

### Application

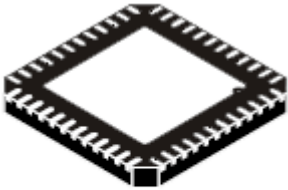
- 32-bit ARM<sup>®</sup> Cortex-M3
  - Scalable up to 100MHz
  - Up to 512kB Flash
  - Code security
  - 4 synchronous serial interfaces SSI
  - 5 UART
  - 2 I<sup>2</sup>C
  - AES128 & 256 encryption (ROM tables)

### Sample Availability 2Q11

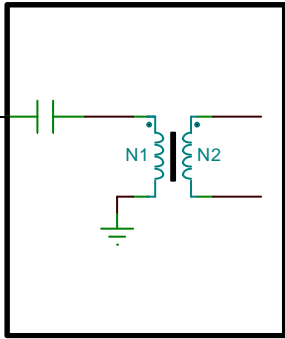


128 QFP 0.4 mm, 144 QFP 0.5 mm  
105°C/125°C and Q100

# Highest Level of Integration and Performance while Maintaining Flexibility

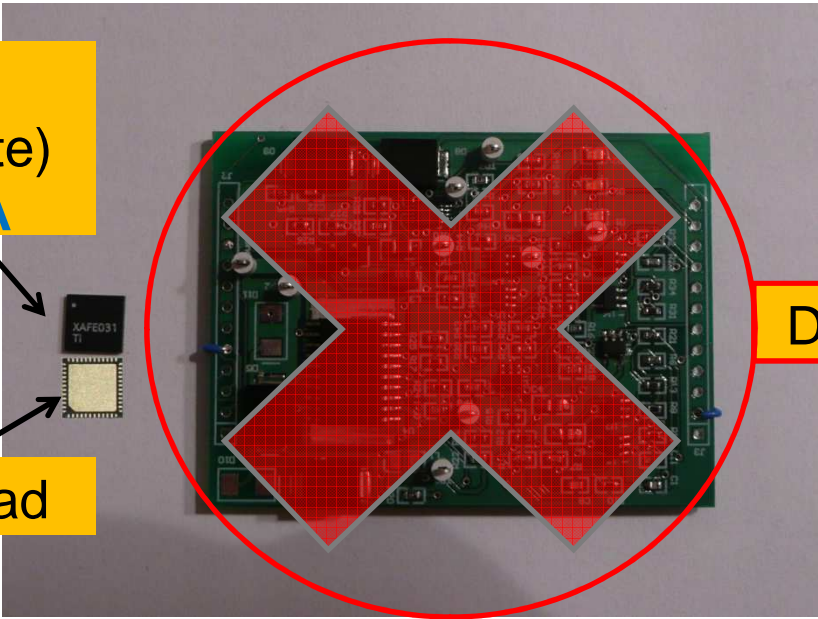


QFN-48  
(7 x 7 mm)



Line Coupling  
Circuit

AFE031  
(replaces discrete)  
**INCLUDES PA**



~~Discrete Analog Front End~~

Large thermal pad



# AFE030

IN PRODUCTION

## Low Cost Fully Integrated PLC Analog Front End

### Features

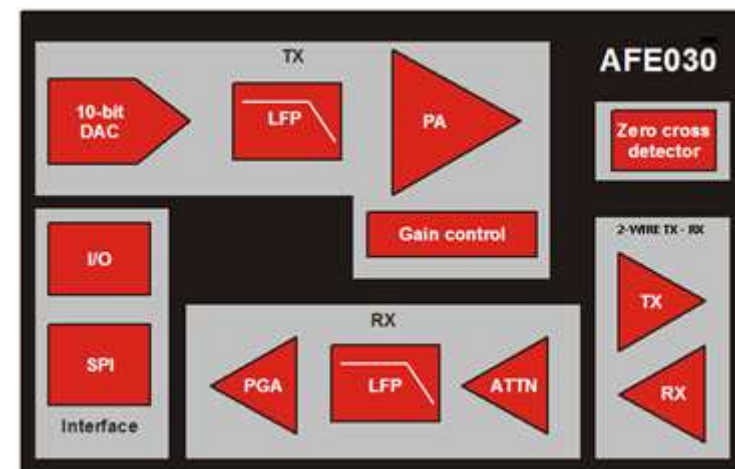
- Highly integrated
  - Integrated programmable TX and RX filters & PGA
  - Two integrated zero-crossing detectors
  - Two-wire transmitter and receiver op-amps
- Highly linear, large output swing power amplifier: 9Vpp @ 1A (12V supply)
- Integrated protection functions
  - Output enable/disable control
  - 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<sub>DD</sub> 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

IN PRODUCTION

## Fully Integrated PLC analog front end

### Features

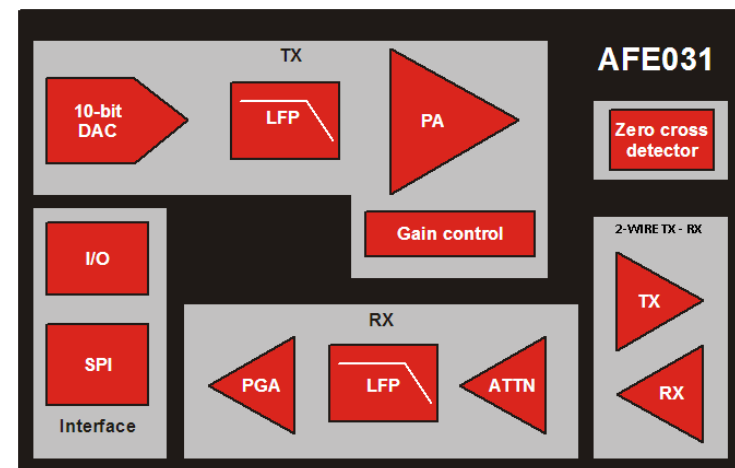
- Highly integrated
  - Integrated programmable TX and RX filters & PGA
  - Two integrated zero-crossing detectors
  - Two-wire transmitter and receiver op-amps
- Highly linear, large output swing power amplifier: 9Vpp @ 1.5A (12V supply)
- Integrated protection functions
  - Output enable/disable control
  - 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<sub>DD</sub> supply (3.3V)
  - Extended -40°C to +125°C temp range
  - Package: 48-pin QFN with Power-Pad

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- E-meters, solar power, HVAC and home automation
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### Benefits

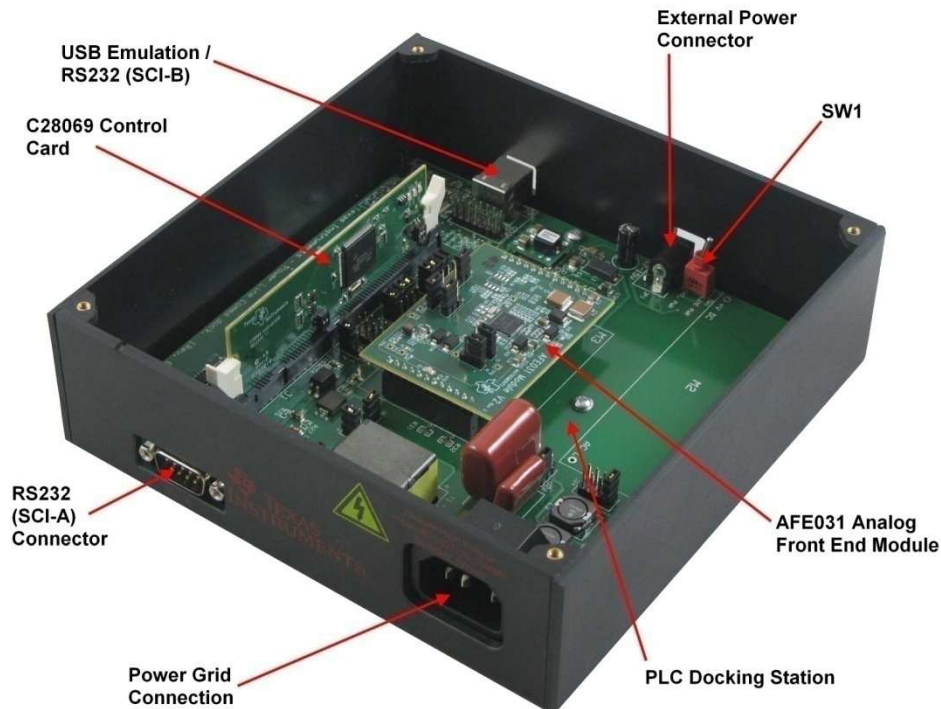
- Flexible and complete AFE solution for PLC
  - Meets and exceeds Cenelec A, B, C and D band requirements as well as PRIME and G3 requirements
  - Enables broadcast of signals using FSK, S-FSK, and OFDM modulation schemes
- Enables end equipment that conform to EN50065-1
- Improves system reliability 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



# 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 (TMDSPCKIT-V3)



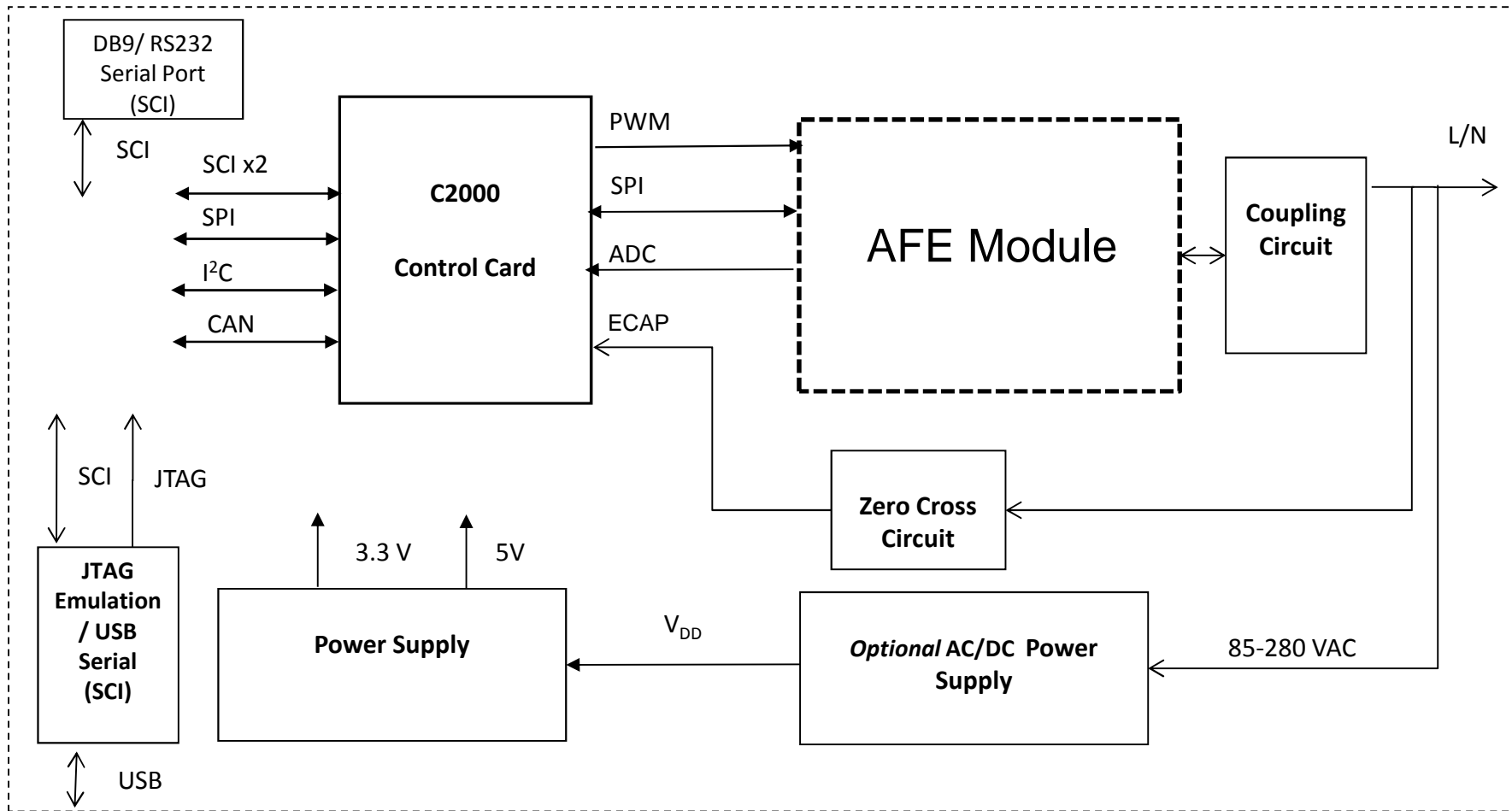
## TI PLC DK contains:

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

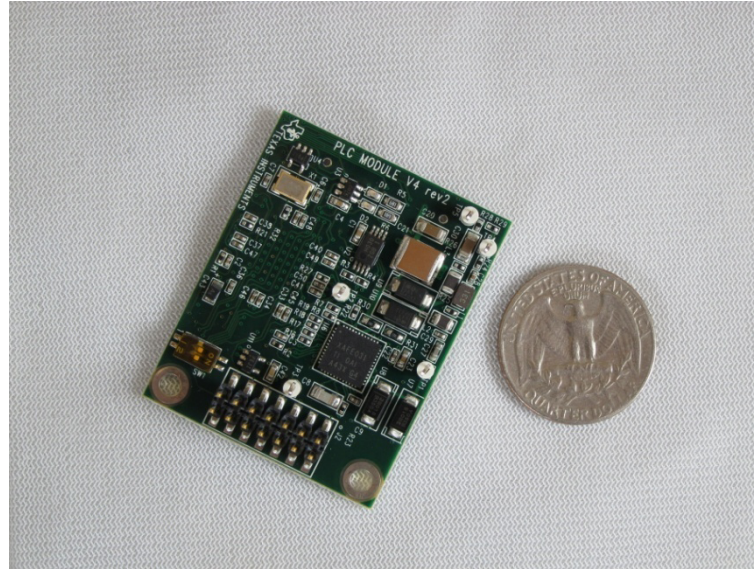
- Robust narrowband PLC modem over low-voltage/medium-voltage power line
- PLC standards/modulation supported
  - PRIME
  - G3
  - FlexOFDM™
- Optional FCC band discrete AFE available
- Compatible with optional Piccolo and Concerto Control Cards

- 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



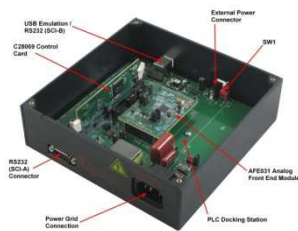
# TI System on Module (SoM)



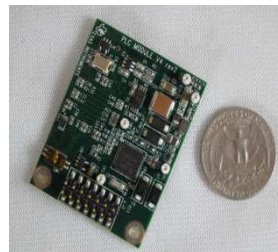
- TI SoM are design suggestions for a more optimized PLC system that can be plugged into an existing application: these are not production proof designs
- TI provides schematics, gerber and layout and can also provide samples
- Feature the F2806x + AFE031 combination
- PiccoloA and PiccoloB SOM versions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

# TI PLC Product Portfolio

Portfolio/Features	F28PLC35/AFE030 (PLC-Lite)	F28PLC83/AFE031 (CEN-A/BCD)	F28M35/AFE032 (FCC)	F28PLC7x/AFE032/ CC1260 (PLC+RF)
Standards/Technologies	FlexOFDM	PRIME/G3/G1/FlexOFDM	P1901.2/G3-FCC	P1901.2/802.15.4g
Max Bit Rate (PHY)	Tl: 21Kbps Other: 2.4-28Kbps	Tl: 64-128Kbps Other: Same	200Kbps	400-500Kbps Other: Same
Frequency Bands supported	CELENEC A, CENELEC BCD half band	CENELEC A, B, C, D With Tone Masks	CENELEC A,B,C,D FCC*, ARIB*	CEN A,B, C, D FCC, ARIB
MCU+AFE Cost	Lowest	Low	Low-Medium	Medium
Maximum CPU Clock Rate	60MHz	90MHz (VCU-I)	150MHz (VCU-I)	150MHz (VCU-II)
IC and Kit Availability	Now	Now	Now (*4Q12)	Q2/2013
TI Product Advantages	<ul style="list-style-type: none"> <li>• low cost with OFDM robustness</li> <li>• FlexOFDM with flexible band selection</li> <li>• Ultra-good NBI performance</li> <li>• CLA for applications</li> <li>• CSMA/CA MAC</li> </ul>	<ul style="list-style-type: none"> <li>• Multiple standards</li> <li>• Certified SW and field proven</li> <li>• Better receiver algorithm</li> <li>• Better network formation algorithm</li> <li>• Simple user interface</li> </ul>	<ul style="list-style-type: none"> <li>• Multiple standards</li> <li>• Higher performance</li> <li>• Additional robust features: Coherent, etc</li> <li>• Adaptive Tone Mask</li> <li>• Field proven</li> </ul>	<ul style="list-style-type: none"> <li>• Industry 1<sup>st</sup> PLC and SDR integrated solution</li> <li>• highest performance for NB-OFDM</li> <li>• OFDM, DSSS, FSK all standard modes</li> <li>• Field tunable</li> </ul>
Target Applications	<ul style="list-style-type: none"> <li>• In-Home-Display to eMeter</li> <li>• eMeter to Collector</li> <li>• Solar inverter connectivity</li> <li>• Home Area Network</li> </ul>	<ul style="list-style-type: none"> <li>• AMR/AMI</li> <li>• IHD/HAN</li> <li>• Energy Gateway</li> </ul>	<ul style="list-style-type: none"> <li>• AMR/AMI</li> <li>• EV/EVSE</li> <li>• IHD/HAN</li> <li>• Energy Gateway</li> </ul>	<ul style="list-style-type: none"> <li>• AMR/AMI</li> <li>• EV/EVSE</li> <li>• IHD/HAN</li> <li>• Energy Gateway</li> </ul>



**TI PLC EVM Kit**



**TI PLC SOM**



**3rd Party PLC Plug-in**

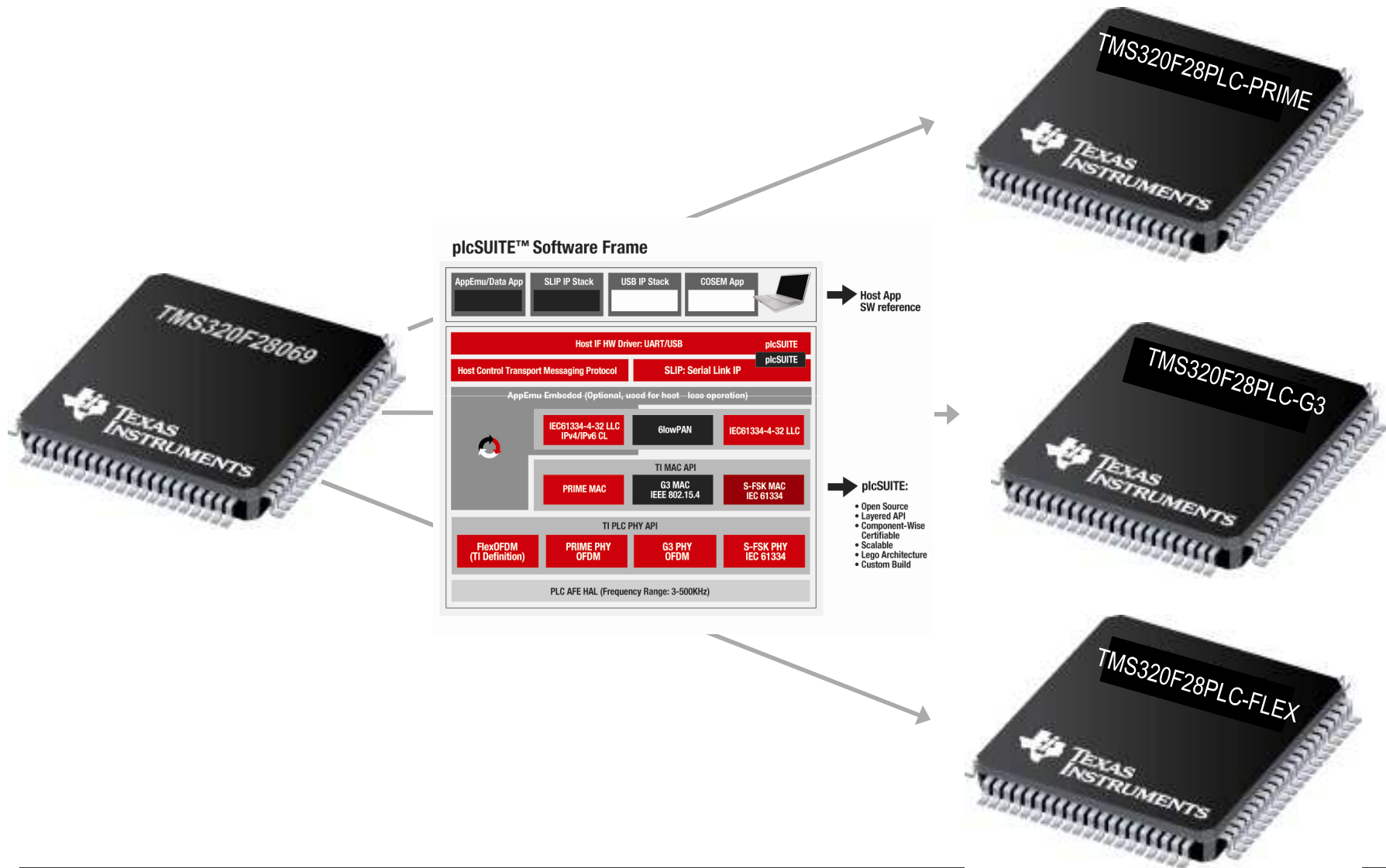


**Data Concentrator EVM**

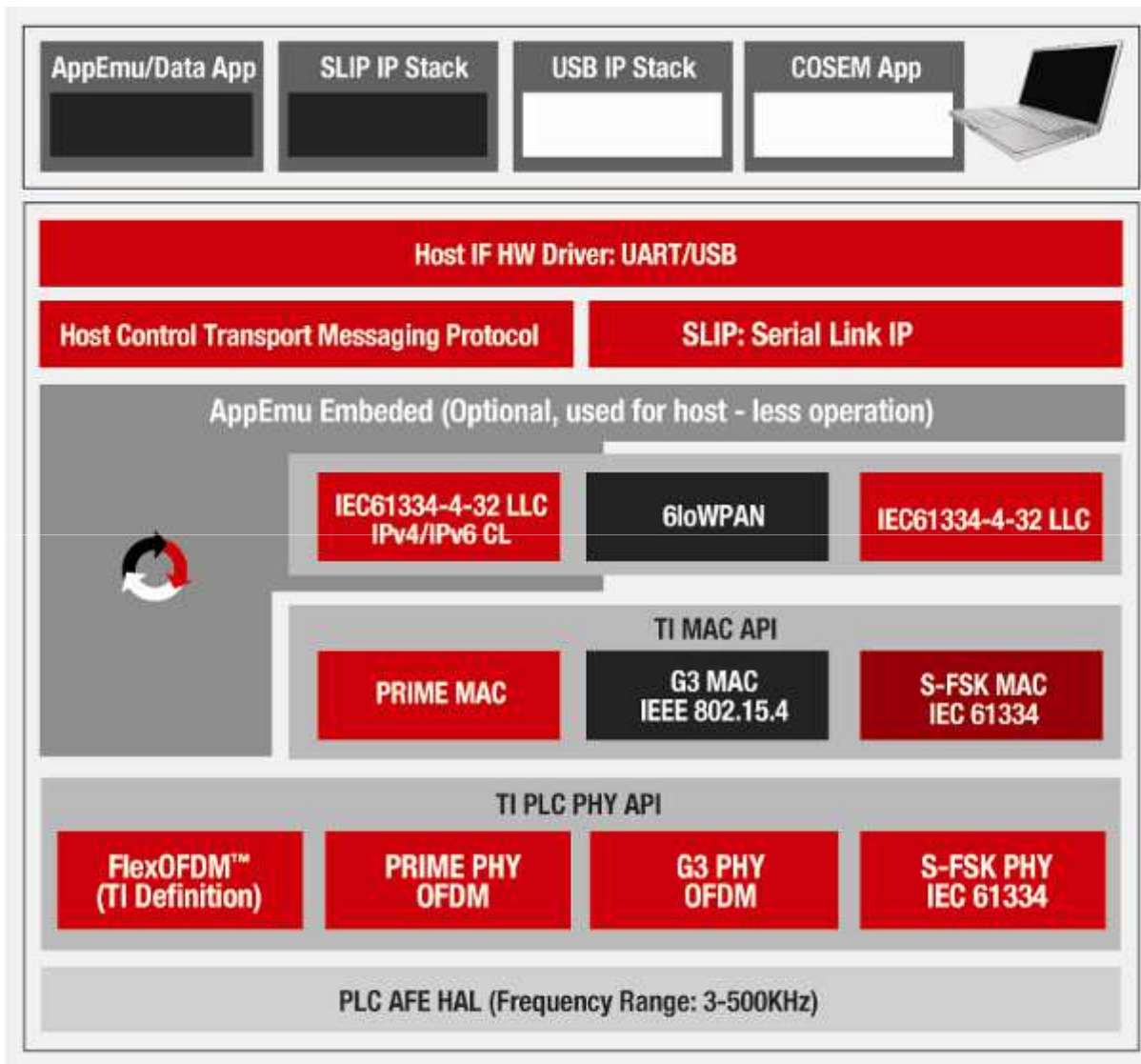
# PLC Software



# Single HW – Multiple Standards



# plcSUITE™ Software Framework



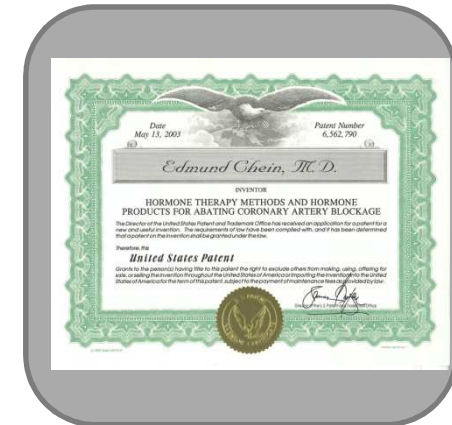
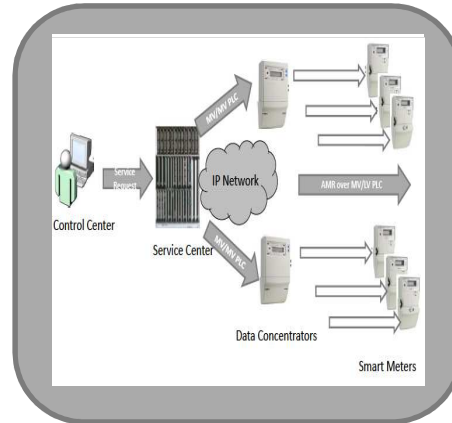
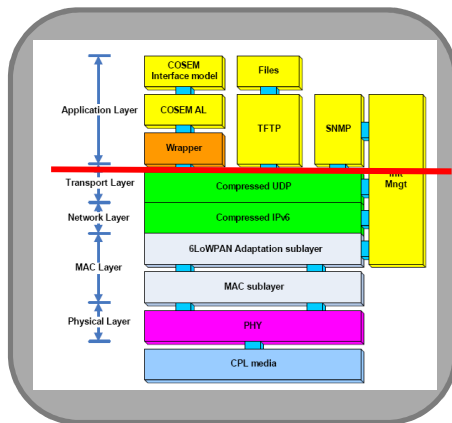
→ Host App  
SW reference

→ plcSUITE:

- Open source
- Layered API
- Component-wise Certifiable
- Scalable
- Lego architecture
- Custom build
- Documentation

# What Customer Wants #1: Time to Market

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



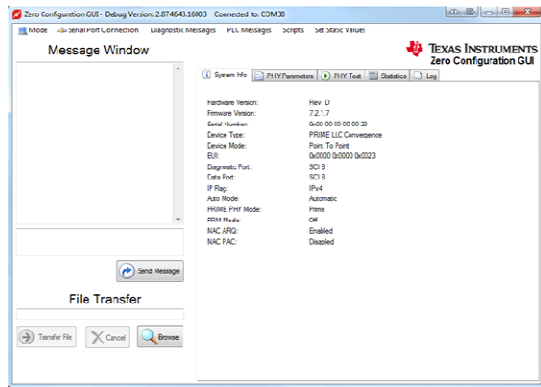
**High Level Integration**

**End-2-End Network Solution**

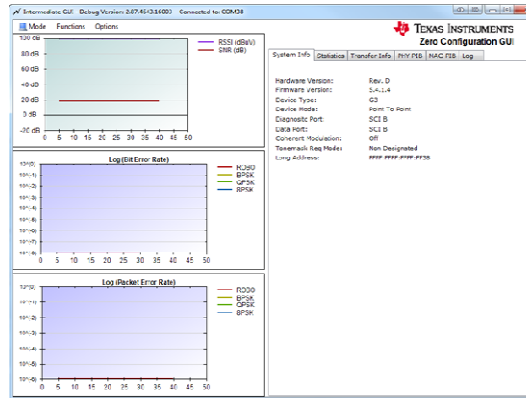
**WW Field test Certification**

**Numerous IPs**

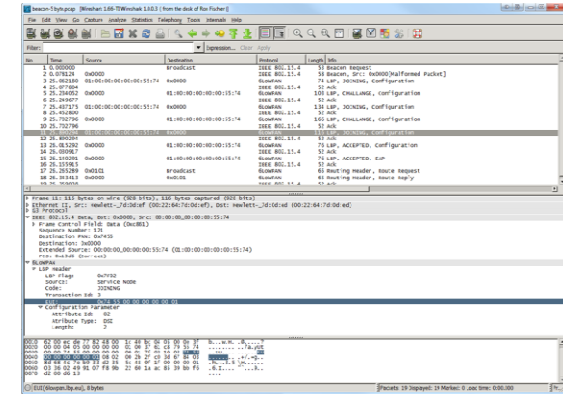
# What Customer Wants #2: Easy to Use



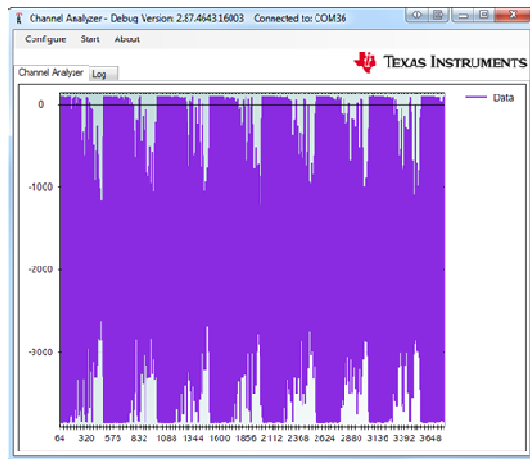
Zero-Config GUI



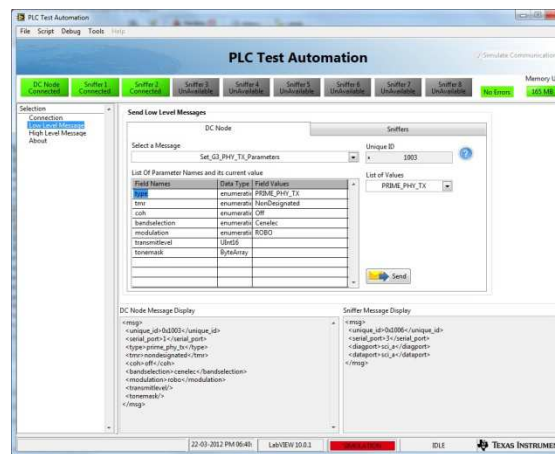
Intermediate GUI



Wireshark Sniffer



Channel Analyzer



Automated Network Tester

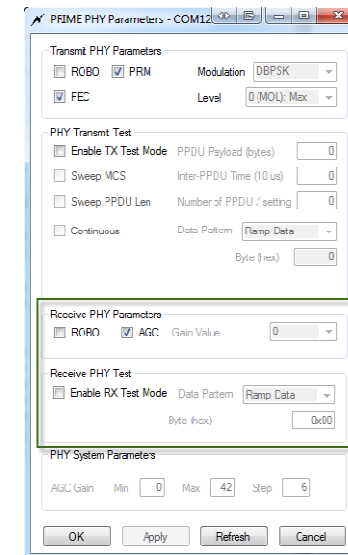
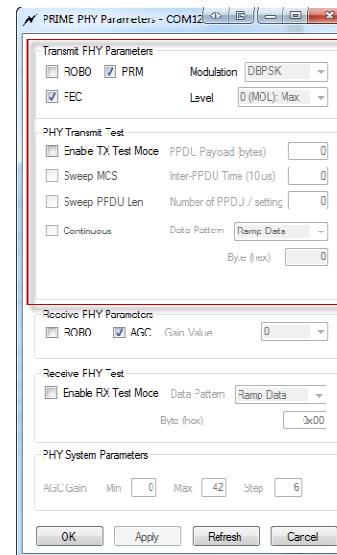
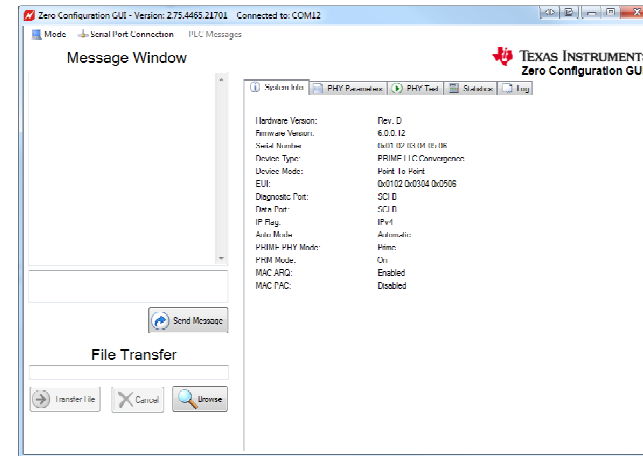
Message Type	PRIME Standard	G3 Standard	Description
0x00	DATA TRANSFER	DATA TRANSFER	Application specific Data messages
0x01	GET_SYSTEM_INFO	GET_SYSTEM_INFO	Get system (HW/SW) info
0x02	GET_PHY_PIB	GET_PHY_PIB	Get PHY PIB attributes from PLC device
0x03	GET_MAC_PIB	GET_MAC_PIB	Get MAC PIB attributes from PLC device
0x04	SET_INFO	SET_INFO	Set certain configuration to PLC device
0x05	SHUTDOWN	SHUTDOWN	Reset PLC device
0x06	SETUP_ALARM	SETUP_ALARM	Setup alarm notifications
0x07	ALARM	ALARM	Alarm Notification
0x08	NW_REGISTER	NETWORK_START	Initiate network registration process
0x09	NW_UNREGISTER		Initiate network un-registration process
0x0a	CONNECT	CONNECT	MAC initiate connection setup process
0x0b	DISCONNECT	DISCONNECT	MAC initiate connection teardown process
0x0c	LOAD_SYSTEM_CONFIG	LOAD_SYSTEM_CONFIG	Load system configuration data
0x0d	SET_MAC_PIB	SET_MAC_PIB	Set MAC PIB attributes from PLC device
0x0e	CLEAR_PHY_PIB	CLEAR_PHY_PIB	Clear certain PHY PIB attributes
0x0f	CLEAR_MAC_PIB	CLEAR_MAC_PIB	Clear certain MAC PIB attributes
0x10	ATTACH		PRIME CL-432 Establish Request and Confirm
0x11	DETACH	DETACH	PRIME CL-432 Release Request and Confirm
0x12		DISCOVER	Network Discovery
0x13	FIRMWARE_UPGRADE		FW Upgrade process
0x14	Get Info	Get Info	Gets miscellaneous PLC data
0x15 - 0x2F	Reserved	Reserved	
0x30 - 0x3F	Reserved	Reserved	
0x80 - 0xfe	Diagnostic messages		
0xff	Reserved		

Table 1 TI PLC Device Host Commands/APIs

HCT Message APIs

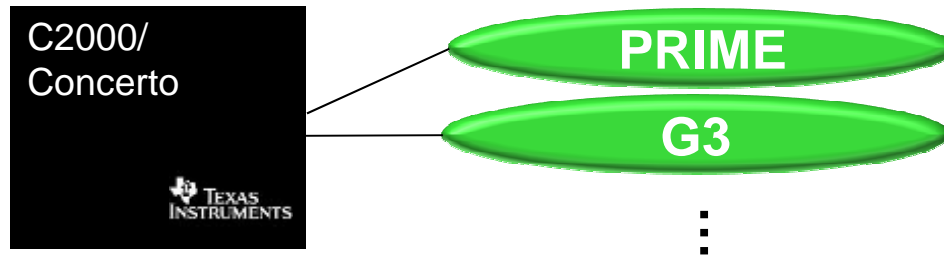
# Enable Customers - Test

- 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

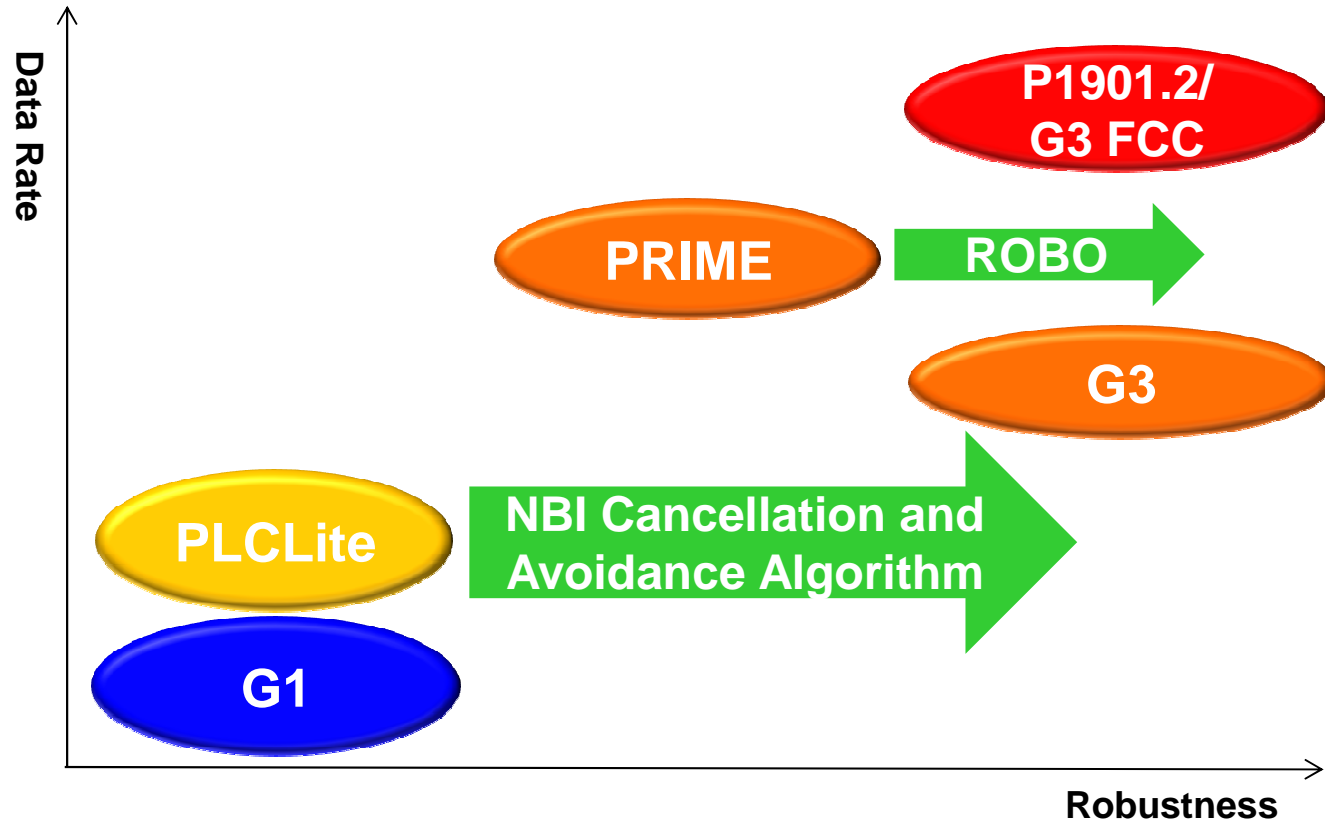




- Enhanced Algorithms inside

PRIME	G3/ G3 FCC/P1901.2	FlexOFDM	PLC-Lite
<ul style="list-style-type: none"> <li>- Beacon search algorithm</li> <li>- Adaptive ARQ timeout</li> <li>- Prioritized Queuing</li> </ul>	<ul style="list-style-type: none"> <li>- Enhanced CSMA/CA</li> </ul>	<ul style="list-style-type: none"> <li>- Adaptive sub-band Selection (up to FCC)</li> </ul>	<ul style="list-style-type: none"> <li>- NBI cancellation algorithm</li> </ul>

- “Easy-to-use” GUI Tool

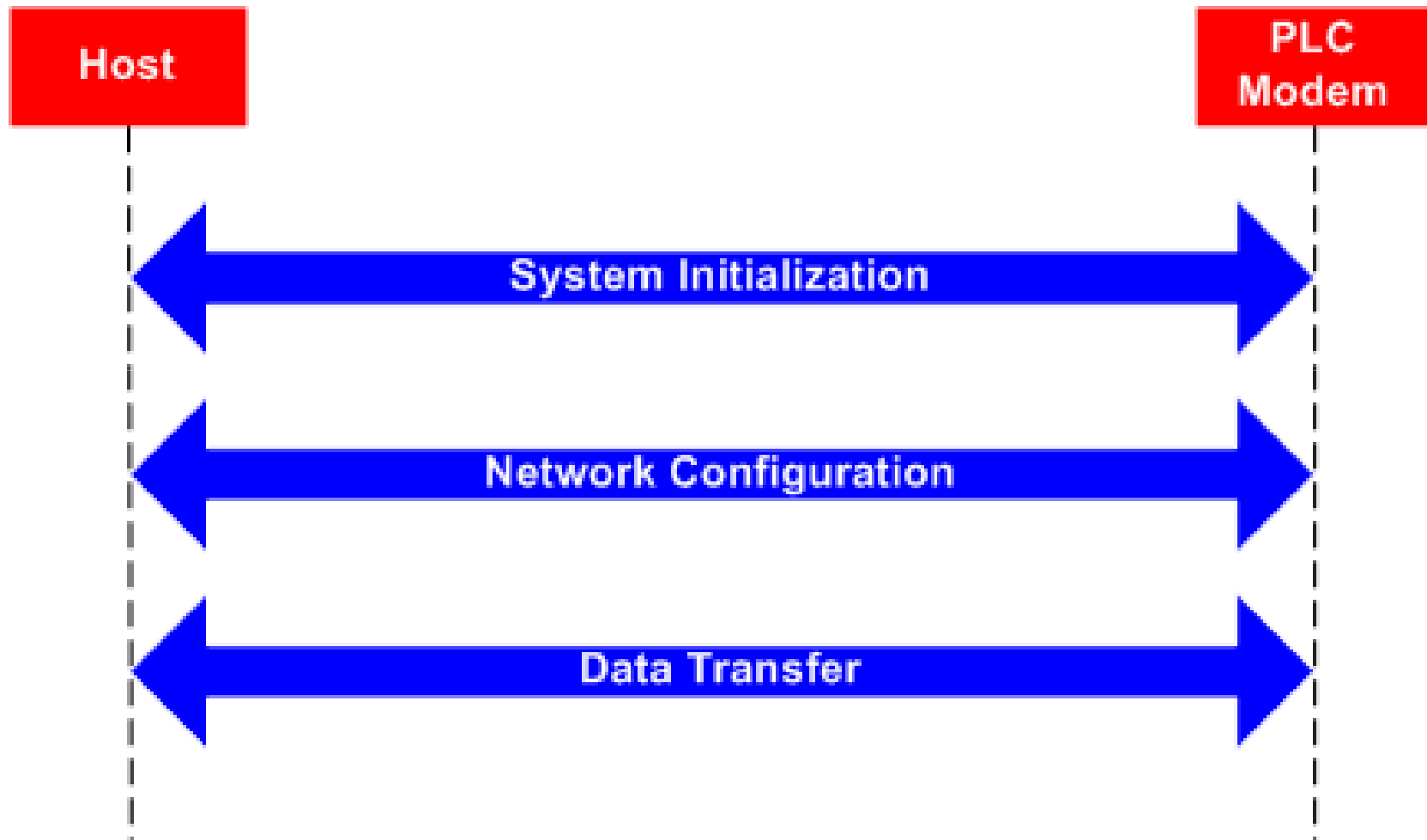
# TI PLC Solutions



 : low  
 : lowest

 : medium  
 : low-medium

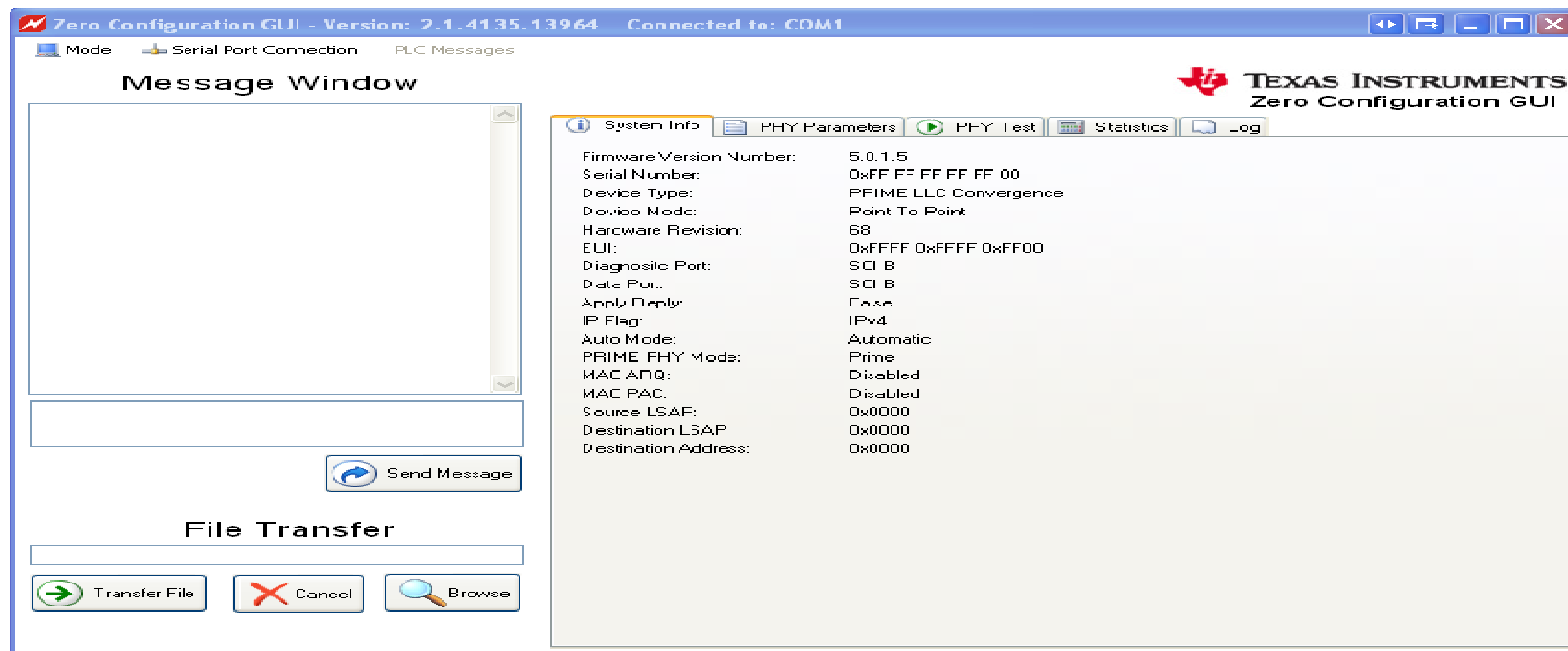
# Message Flow Overview (G3/PRIME)





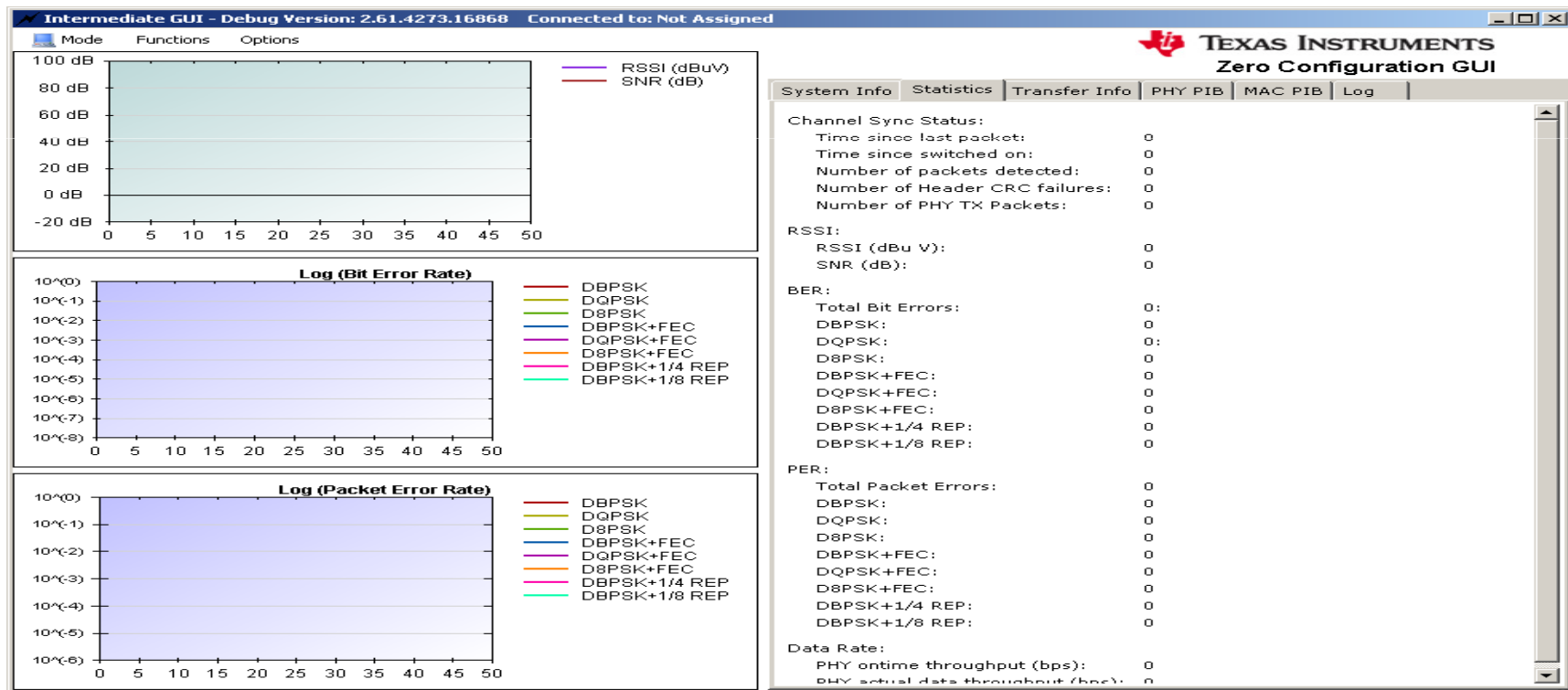
# Zero-Configuration GUI

- 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

Standards/Platform	F28027 (Piccolo-A)	F28035 (Piccolo-B)	F28069 (Octave)	F28M35 (Concerto)	AM180x/L138 +F28069(Octave)
IEC 61334-5-1 PHY,MAC (S-FSK)	Now	N/A	N/A	N/A	N/A
PRIME PHY, MAC, CS IEC 61334-4-32 LLC	N/A	N/A	Now (v6.0.0.13)	3Q12 IPv6, PRIME FCC	PRIME DC baseline (v3.0.0.0) Now
G3 (OFDM)	N/A	N/A	Now (v5.0.0.0)	Now (v5.0.0.0) Cenelec A/B/C/D, FCC	G3 DC baseline (v2.1.0.0) Now
P1901.2 (OFDM)	N/A	N/A	N/A	1Q12	N/A
FlexOFDM (Proprietary flexible OFDM implementation)	N/A	N/A	N/A	1Q12	N/A
PLC Lite (light version of FlexOFDM, MAC/PHY)	1Q 12	Now (v3.0.0.0) Cenelec A/BCD Band	N/A	N/A	N/A
MCU + AFE Cost	Lowest	Low	Low-Medium	Medium	Medium-High
Frequency Bands supported	CENELEC A	CENELEC A,B,C,D	CENELEC A,B,C,D	CENELEC A,B,C,D FCC, ARIB	CENELEC A,B,C,D FCC, ARIB
Max Bit Rate (PHY)	2.4kbps	22kbps	200kbps	500kbps	

- \* 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)