Reliable Power Line Communication

– A Vehicle to Smart Meter, Smart Home and Smart Grid

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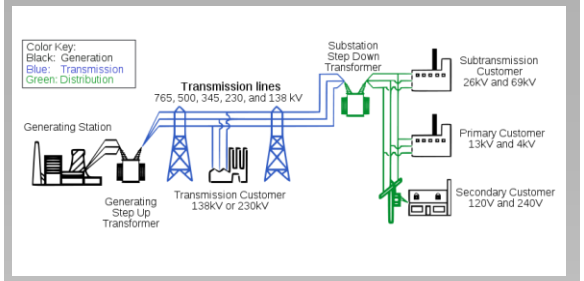
Agenda

- Power Line Communication for smart meter, home and grid
- Key Challenges and Requirements
- Select Scalable PLC Solutions
- Future PLC Research Areas

Power Line Communication for Smart Meter, Smart Home and Smart Grid

PLC Is Key Technology in Meter, Home, Grid

Smart Grid infrastructure



- **Data Concentrators**
- **Medium/High Voltage Backbone Network**
- **Repeaters/Gateways**

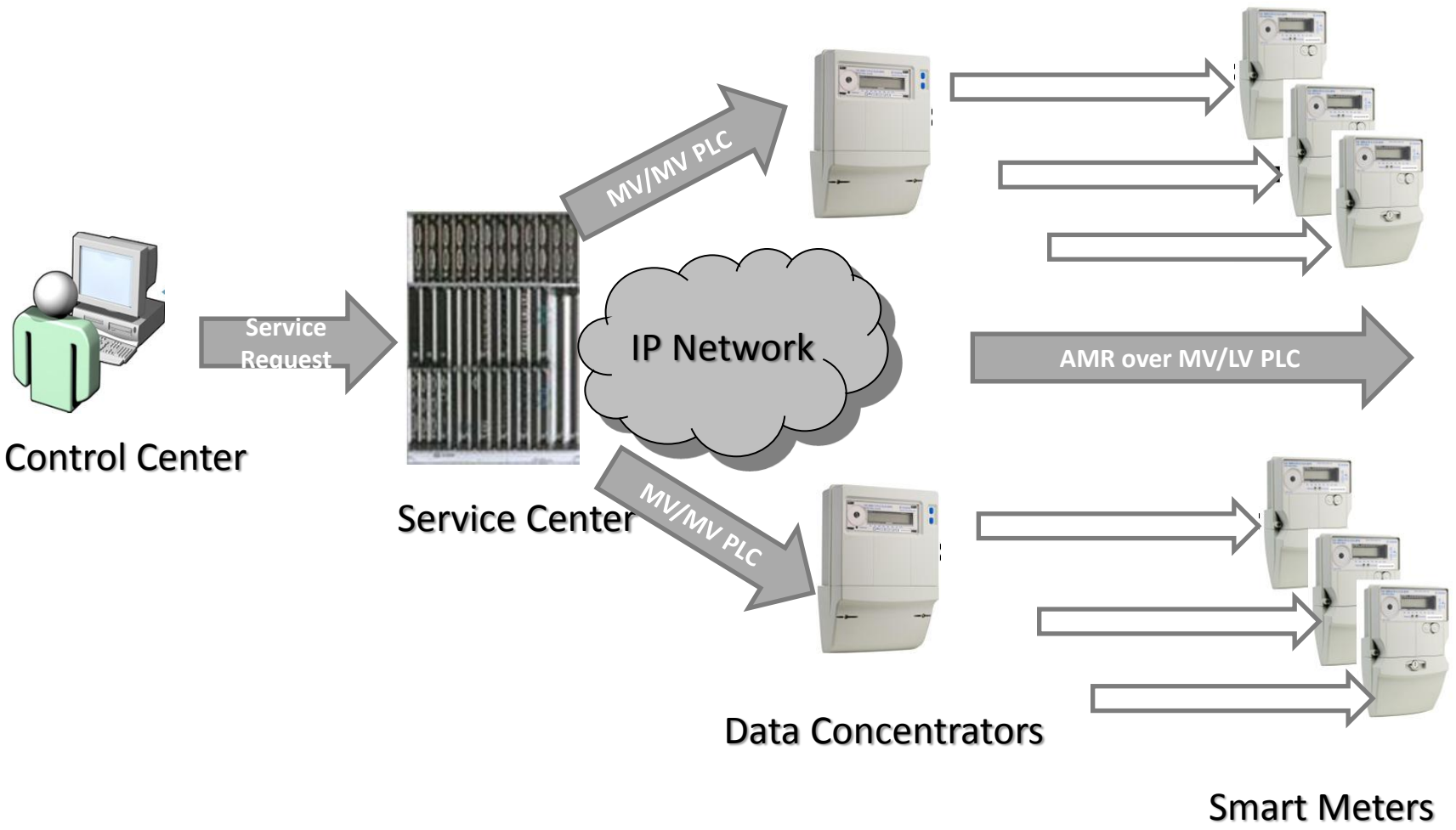
Smart Meters

- **eMeter COM module**
- **RF/PLC Gateway**
- **RF/PLC Combo module**

Smart homes and buildings

- **eMeter to smart appliances**
- **In-home display &Thermostats coms**
- **Sensor Network backbone/overlay**
- **EV/EVSE**

PLC for Smart Meter Application

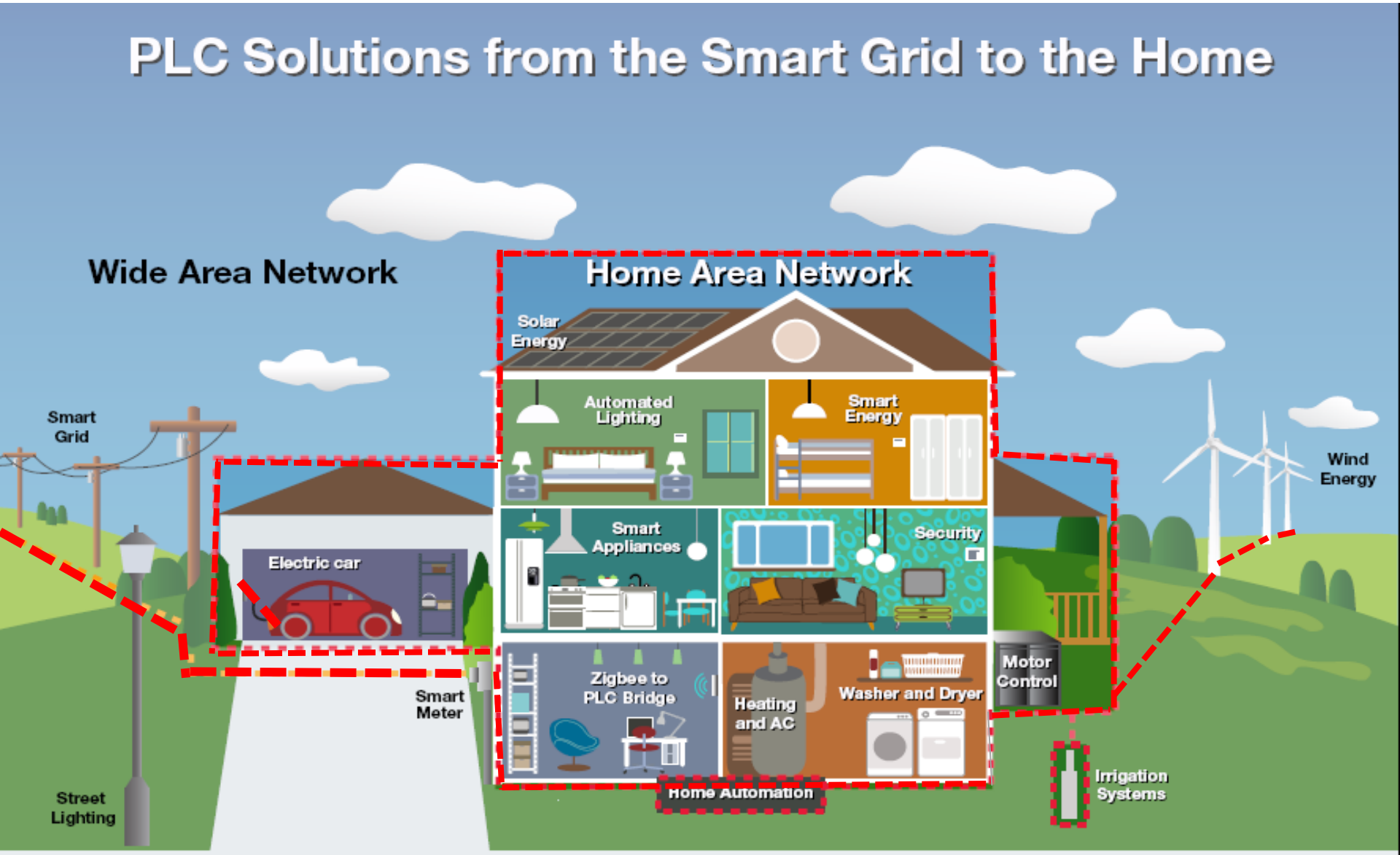


PLC For Hybrid Sensor Networks

Further increase **robustness** and **scalability** of sensor networks for smart home

A wireless sensor network use-case from Panasonic

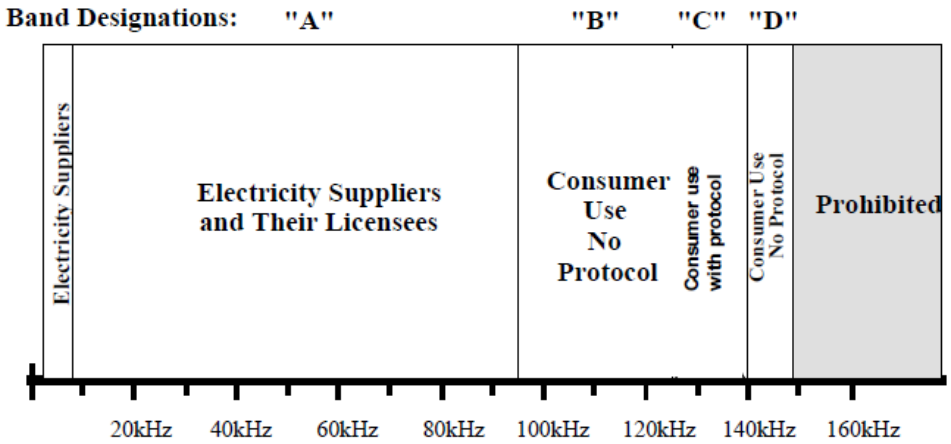
Smart Grid Rejuvenates the PLC



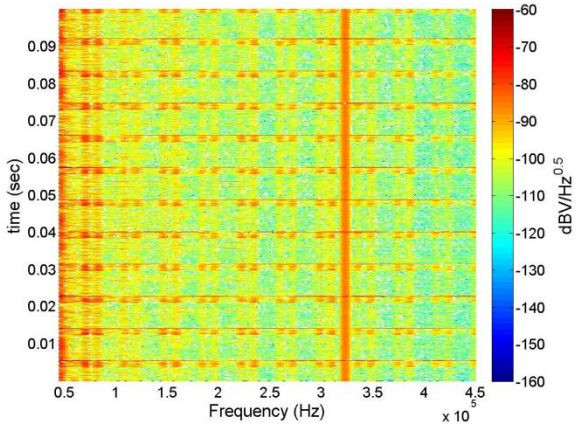
Key Challenges and Requirements

Scalable PLC Technology for Future SG

- **Focus on frequencies <500KHz**
  - Propagation, cost , Reliability
- **Meet country specific regulations**
  - EMC / emissions
  - ARIB, FCC, CENELEC
- **PLC network throughput/stability/capacity**
  - Network topologies and coverage
  - Meter reading success rate
  - Deal with difficult locations
  - Error recovery
- **Physical Characteristics**
  - Band agility and cognition
  - OFDM based technology
  - Understand channel model
- **Deal with Variations**
  - Variable standards
  - Variable geographical features
  - Variable application frameworks



- **Europe: CEN-A for utility**
- **Japan: ARIB 10kHz – 450kHz**
- **US, China, India: FCC 3kHz – 500kHz**



MV-LV crossing Transformer Channel Model

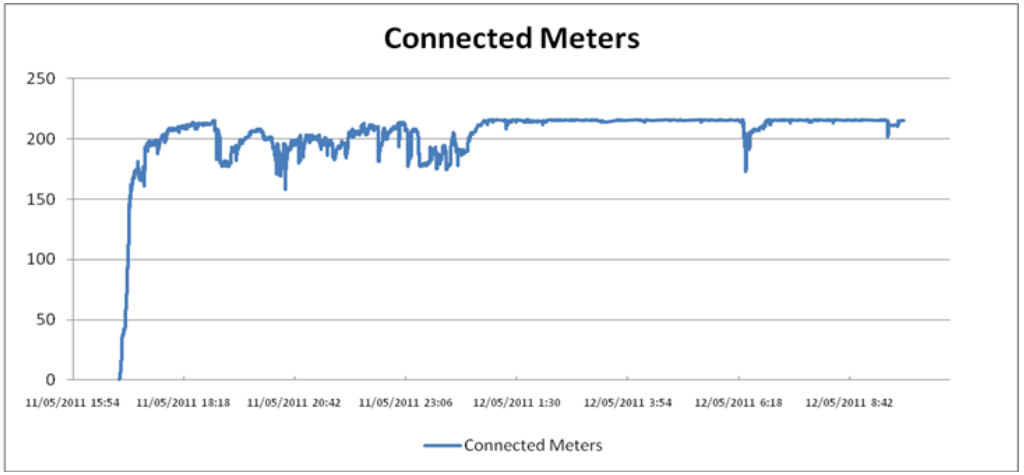
G3-ROBO in CEN-A 36 Field Tests in Tangshan, China

TX Phase	RX Phase	Time	RX Row	Distance	PHY Test Transformer ->Terminal ROBO A-36, TX Level: 32	PHY Test Terminal ->Transformer Robo, A-36, TX level:32	Message Transfer Transformer-> Terminal Robo, A-36, TX level:32	Message Transfer Terminal ->Transformer Robo, A-36, TX level:32
C	C	10:50AM	12	30m	BER:0 FER:0	BER:0 PER:0	Yes	Yes
C	B	11:00AM	13	50m	BER:0 PER:0	BER:0 PER:0	Yes	Yes
C	B	11:07AM	14	70m	BER:0.13% PER:4.5%	Can not communicate	Yes	No
A	A	11:12AM	15	90m	BER:0% PER:0%	Can not communicate	Yes	No
A	B	11:30AM	16	110m	BER:23% PER:100%	Can not communicate	No	No
A	A	11:37AM	17	130m	BER:1% PER:25%	Can not communicate	Yes	No
A	A	11:44AM	19	150m	Can not communicate	Can not communicate	No	No
B	B	13:39PM	18	170m	BER:0% PER:0%	BER:0% PER:0%	Yes	Yes
A	A	13:49PM	19	190m	BER:0% PER:0%	BER:0% PER:0%	Yes	Yes
B	B	14:00PM	21	210m	BER:0% PER:0%	Can not communicate	Yes	No
B	B	17:20PM	14	70m	BER: 0% PER: 0%	Can not communicate	Yes	No
A	A	17:35PM	15	90m	BER: 0% PER: 0%	Can not communicate	Yes	No
C	B	17:45PM	13	50m	BER:0 PER:0	Can not communicate	Yes	No
B	B	17:50PM	13	50m	BER:0 PER:0	Can not communicate	Yes	No
B	B	17:55PM	13	50m	BER:0 PER:0	BER:0 PER:0	Yes	Yes
B	B	18:00PM	14	70m	BER:0 PER:0	Can not communicate	Yes	No
B	B	18:15PM	NA	140m	BER:0 PER:0	Can not communicate	Yes	No

- Channel Asymmetric Feature
- Time Variations
- Band agility, Tone Mask Settings

TI PRIME Meters in Burriana, Spain

- **Network Capacity: Maximum number of meters supported in single AMI network**
- **Connectivity: >99%**
- **Meter Reading Success Rate: >99%**
- **Routing efficiently: max number of hops**
- **Network Stability**



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Multiple PLC Standards Comparisons

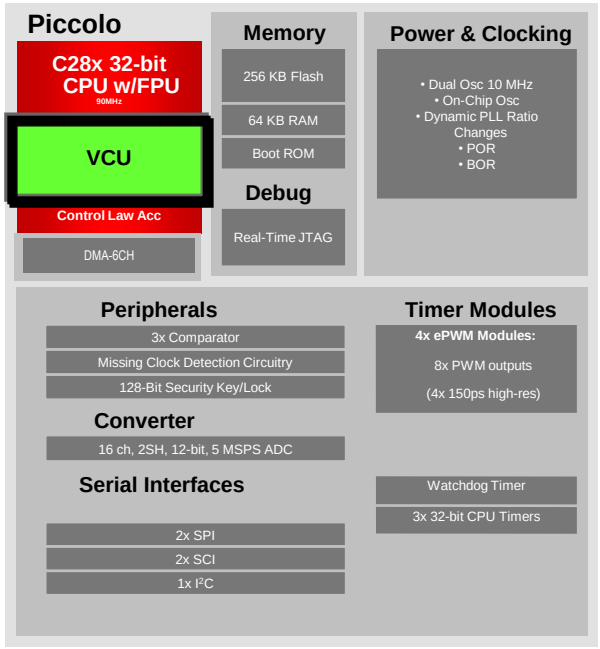
Parameter	IEC61334 S-FSK	PRIME(OFDM)	G3(OFDM)	P1901.2(OFDM)
Modulation Size	Spread Frequency Shift Keying	DBPSK / DQPSK/D8PSK	DBPSK / DQPSK/D8PSK	DBPSK/DQPSK/D8PSK/ Coherent Modulation
Forward Error Correction	N/A	Rate ½ convolutional Code	Outer RS + inner rate ½ convolutional code	Outer RS + inner rate ½ convolution code
Data Rate	2.4Kbps	21, 42, 64, 84, 128 Kbps (w/ and w/o coding)	20.36, 34.76, 46 Kbps (with coding)	Scalable up to 250Kbps
Band plan	CENELEC-A	Continuous 42-89 KHz (defined for LV scenario)	36-91 KHz with tone masking for SFSK	CENELEC/FCC band
ROBO Mode	No	No	Yes	Yes
Tone Mask	No	No	Yes	Yes
Adaptive Tone Map	No	No	Yes	Yes
MAC	IEC61334 MAC	PRIME MAC	802.15.4/G3 profile	802.15.4 based
Convergence Layer	IEC61334-4-32	IEC61334-4-32/IPv6	6LoWPAN/IPv6	6LoWPAN/IPv6

A Single HW Platform Can Support them All?

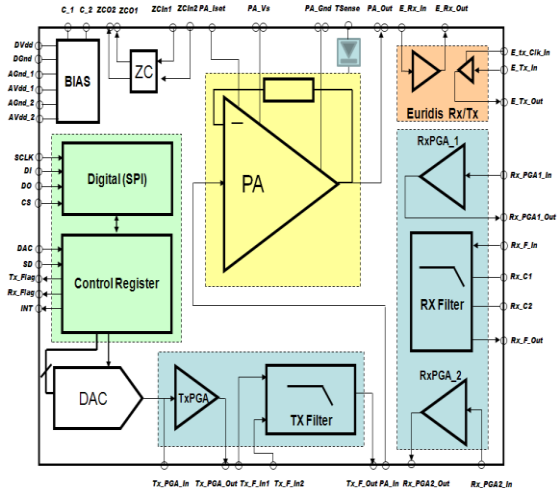
Select Scalable PLC Solutions

Selecting the Best PLC Technology for Scalability

- **NB OFDM**
  - Standards momentum
  - R&D investment
  - Flexible bandwidth
  - Low MIPS frequency domain processing for interference mitigation
- **OFDM vs. Single Carrier**
  - n*log(n) vs. n^2 MIPS
  - Frequency domain processing
  - Scale bandwidths, #subcarriers
  - Frequency domain sync
  - Single carrier, short symbols, higher overhead in MCU/DSP
  - Higher PAR, but averaged transmit power is similar
- **OFDM Software**
  - Full reuse of software libraries
  - Software portable between MCU family members: low cost vs. high performance



OFDM MCU



Integrated AFE

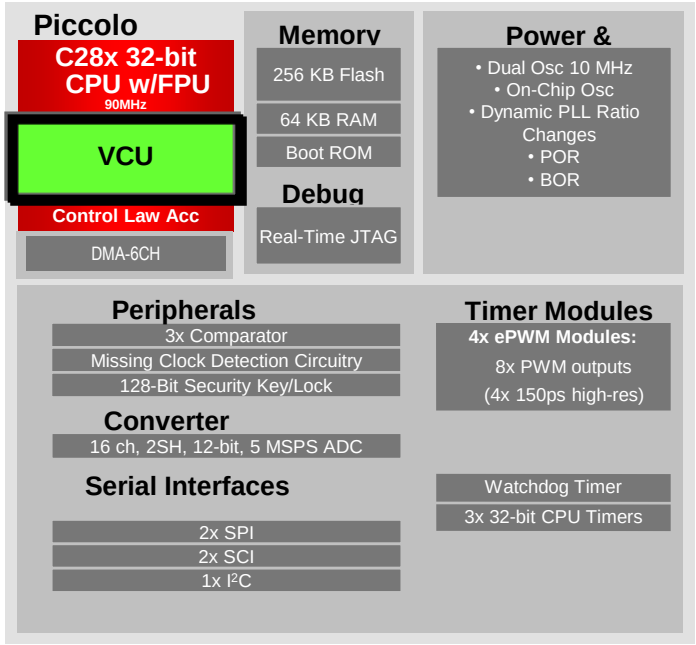
PRIME **G3-PLC** **ITU-T G.9955/56**

IEEE P1901.2 **Scalable OFDM**

Narrowband OFDM Technologies

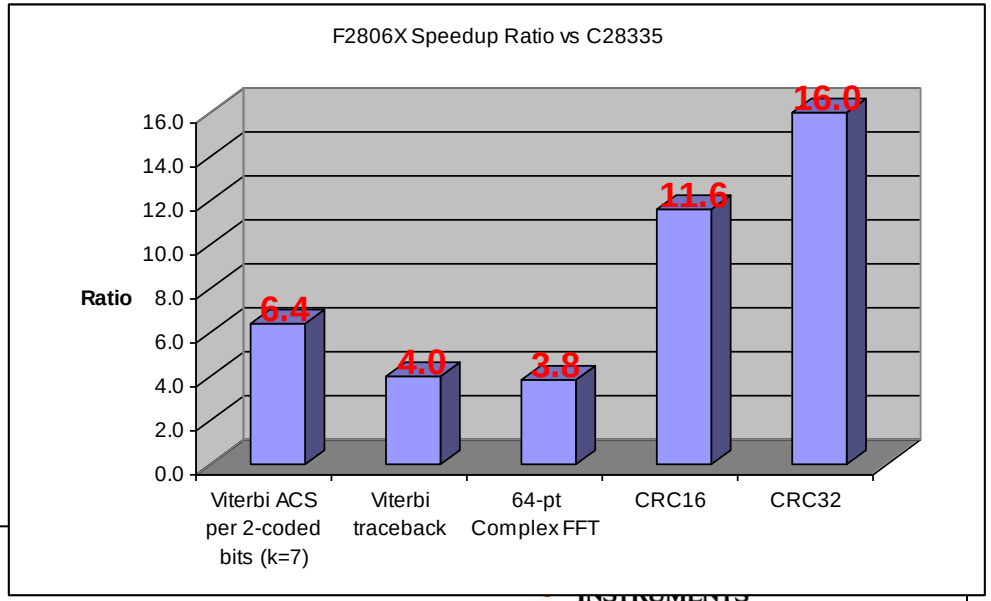
Application-specific Instructions in OFDM MCU

- **OFDM MCU Provides:**
  - **Special instructions** to accelerate PLC
    - **FEC** computations (Viterbi acceleration, Galois field arithmetic)
    - **FFT/IFFT** acceleration
    - **Complex arithmetic**
    - **Security engine** (CRC, other instructions to accelerate AES computations)
  - Instructions accelerate frequently used computations (90% of the computations are in 10% of the functions)



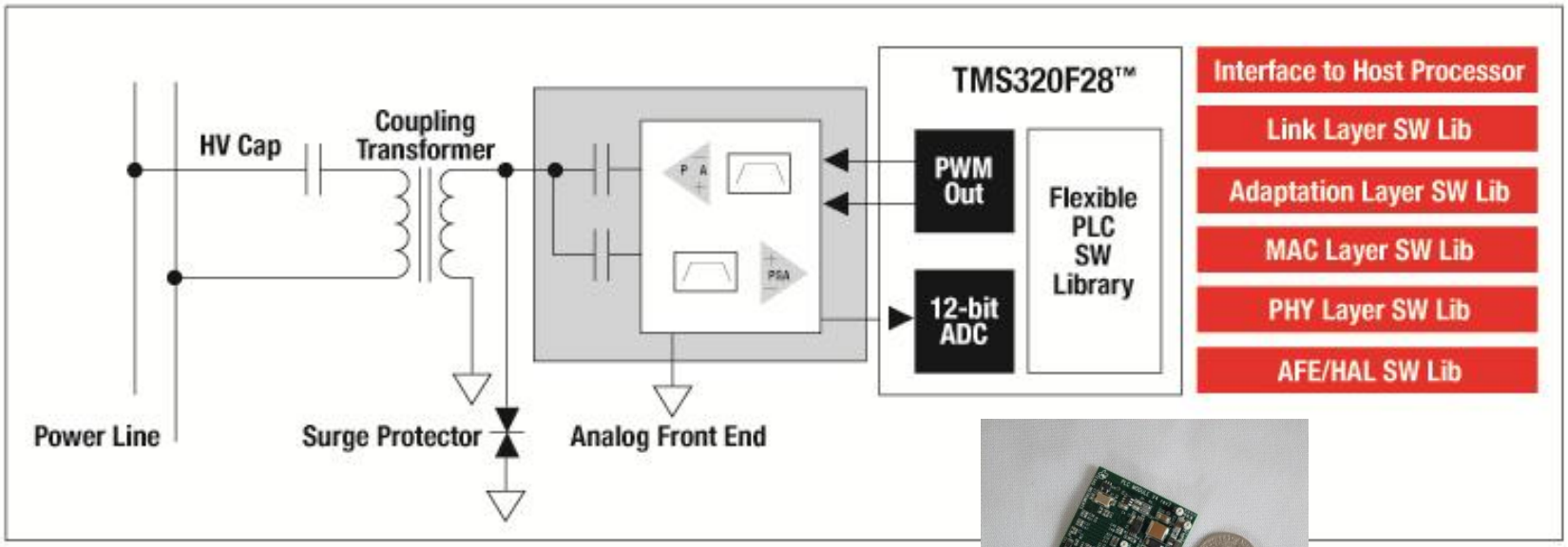
OFDM MCU

- **Benefits**
  - **Competes with custom ASIC** in terms of cost and power dissipation while **achieving full programmability**
  - Lower cost and power than a general purpose DSP / MCU
  - Ability to evolve implementations as PLC standards evolve

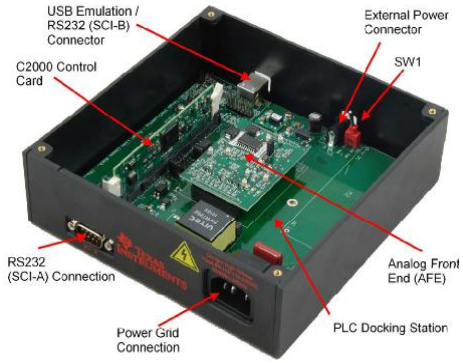


TI PLC Development Kit

TI Narrowband PLC Solution
Flexible, scalable and easy to customize



- **Flexible Hardware**: Single HW Digital + AFE support
  - Frequency (0-500KHz)
  - C2000 family: F2806x for CEN-A, F28M35x for FCC
  - AFE030/AFE031: CEN-A/B/C/D, AFE032: FCC
- **Complete SW Package Development Kit**: plcSUITE
  - Standards: PRIME, G3, P1901.2, IEC61334 (S-FSK)
  - Open platform with certified SW Libs
- **Support Customization**: FlexOFDM



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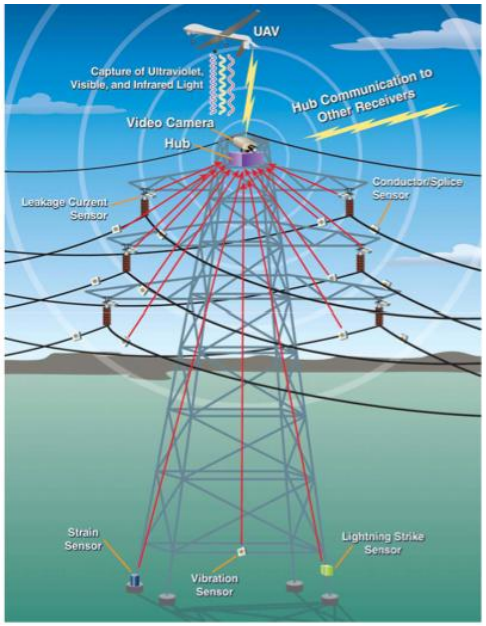
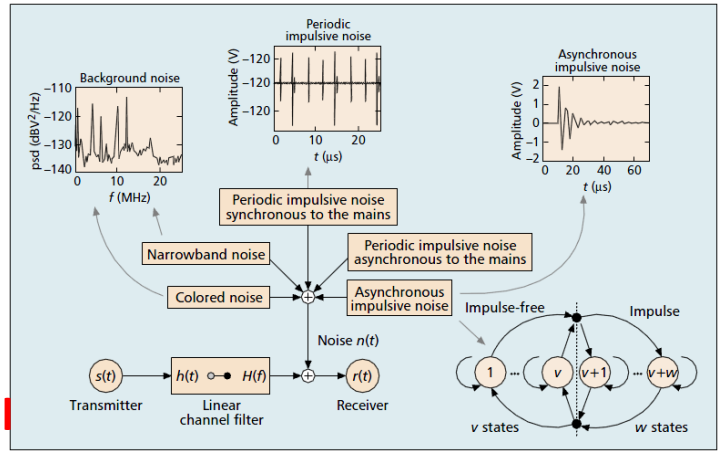
Future Research Areas

PLC Future Research Areas

- **Smart Grid PLC:**
  - **Further mature deployment of MV-LV transformer crossing technology**
  - **Use of NB PLC for MV-MV WAN Usage to Connect DC to Substation or Meter to Substation**
  - **Connect Grid Heath Sensor Cloud**
  - **Cognitive PLC for band agility**
- **Smart Home PLC:**
  - **PLC control network integrated with sensing or monitoring network**
  - **PLC/RF combo node for extra-robustness and lower power sensing**
- **PLC Channel Modeling Study**



Grid Sensor Cloud



PLC Channel Model

Conclusion

- Narrow Band OFDM Based PLC provides solution for future smart meter, home, grid applications
- International standards (PRIME, G3, IEEE P1901.2, G.9955/56) all supports NB OFDM based PLC
- A flexible, multi-standard enabled PLC solution provides best return on investment
- As PLC narrow band gaining the market acceptance, new application areas are evolving: EV/EVSE, lighting, industrial/home automation, etc.
- PLC needs to be continuously evolving for more and more robust to meet all these application requirements