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POWER-LINE COMMUNICATIONS EMERGE AS A CORE NETWORKING TECHNOLOGY

As concerns about interference, noise, and attenuation are addressed, new standards expand PLC's role in the home and industry.

Selecting a communications method for an application today has never been easier. Besides wired methods like Ethernet, unshielded twisted pair with RS-485, or coax, wireless tends to stand out because of its convenience and low cost.

However, designers sometimes overlook power-line communications (PLC), which uses available ac power lines as the communications medium. Power lines exist practically everywhere and are certainly convenient.

Like wireless, you don't have to install or otherwise fuss with the medium. It's just there. But you do have to be aware of issues like noise and severe attenuation, which are common to any communications technique.

The idea of using the power line as a communications path has been explored for decades with varying success. With new standards and technologies, it's an even better choice than it was before. In fact, multiple chip and equipment vendors have adopted PLC *(see "New Products Jump On The PLC Bandwagon," p. 44)*.

THE CONCEPT

PLC uses the existing ac power mains as a communications channel. Data is superimposed on the 50- or 60-Hz ac. The communicated data first is used to modulate a carrier, and the carrier rides on the ac voltage.

Amplitude shift keying (ASK) has been used for this purpose. For example, the X10 home lighting and control system has been in use since the 1970s. Binary coded pulses modulate a 120-kHz sine carrier using ASK or on-off keying (OOK) at about 20 bits per second.

Frequency shift keying (FSK) has also been used because of its higher immunity to noise. Binary phase shift keying (BPSK) is used too, as are various spread-spectrum technologies. Today, newer PLC systems use orthogonal frequency division multiplexing (OFDM) for higher speeds and improved noise mitigation.

Figure 1 illustrates a typical PLC network. The upper part shows the medium-voltage (MV) power line (1 to 72 kV) from the utility substation. It feeds multiple neighborhood MV to low-voltage (LV) step-down transformers that reside on poles or concrete slabs. These transformers feed multiple homes with 240-V ac center tapped into two 120-V lines.

Each home has an electric meter. Assume that these meters are advanced metering infrastructure (AMI) models that measure and transmit energy usage to the utility via PLC. A data concentrator may be attached to the LV side of the transformer to collect the data from multiple homes and aggregate it for transmission back to the utility.

In some cases, the concentrator may be on the MV side aggregating data from multiple LV transformers and homes. The concentrator transmits data back to the utility via wireless such as cellular or WiMAX or other high-speed connections like DSL or fiber.

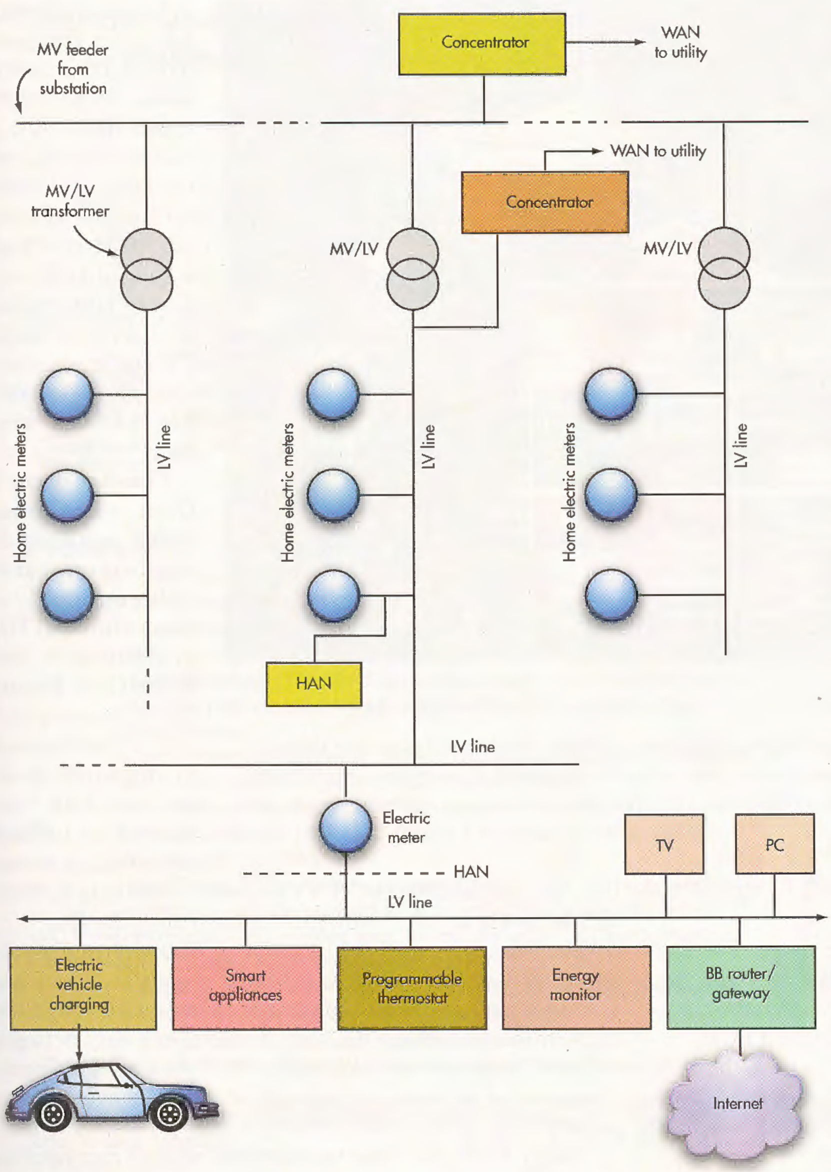
Some homes may have a home-area network (HAN) using PLC *(Fig. 2)*. The home LV line is the communications channel for vehicle charging, smart appliances (hot water heater, dryer, washer, etc.), a programmable HVAC thermostat, a home energy monitor, and other devices. The home LV line also may be used for high-speed data.

A broadband (BB) gateway or router connected to the Internet via DSL, cable TV, or other source feeds data to personal computers and HDTV sets. Video and Internet data also travels over the LV line.

THE DESIGN ISSUES

While PLC is convenient and can save money, it has its limitations. First, the medium was designed to carry 50- or 60-Hz ac but is unfriendly to higher frequencies. Higher-frequency carrier signals are severely attenuated. This limits the range of any transmission.

Second, such high-frequency signals must sometimes be transmitted through a transformer. Power-line step-down transformers additionally introduce extreme attenuation to any modulated carrier. Furthermore, modulated carriers may



1. A typical PLC network involves the utility (top) and the home-area network (bottom).

from the ac line can interfere with any transmitted signal as well. Such low-level noise generally causes noise of several volts or more.

PLC was once hyped as a broadband technology for high-speed Internet access. Local electrical utilities implemented several systems. Called broadband over power line (BPL), it was never possible to achieve speeds greater than several hundred thousand bits per second and was generally unacceptable as an Internet service.

On top of that, these systems caused massive interference to shortwave-range (3 to 30 MHz) radio signals including amateur radio, rendering them useless. After many complaints, the Federal Communications Commission killed these systems.

Today, such interference is still possible from some systems. It's generally contained within a building or other limited space, though, so it doesn't cause widespread interference as extensive ac power distribution lines in a city or county would cause.

PLC transceivers must be extremely robust and factor in high transmission power, filtering, special modulation methods (frequency hopping, spread spectrum, orthogonal frequency division multiplexing or OFDM, etc.), error detection and correction methods, and other techniques to overcome these problems.

have to bridge from one ac phase to another, which complicates the transmission.

Attenuation averages 10 to 30 dB/kilometer on LV lines (< 1 kV) and about 100 dB/km on MV and high-voltage (HV) lines (>10 kV), not including phase bridging or transformers. The attenuation varies widely with the frequencies used, modulation methods, transmission line length, and noise conditions at different times of day.

Also, power lines carry a considerable amount of noise generated by switching transients, lightning, appliances (hairdryers, toothbrushes, shavers), anything with a motor (vacuum cleaners, dishwashers), switch-mode power supplies, fluorescent lights and compact fluorescent lamps (CFLs), light dimmers, TV sets, and other loads that aren't filtered. Harmonics

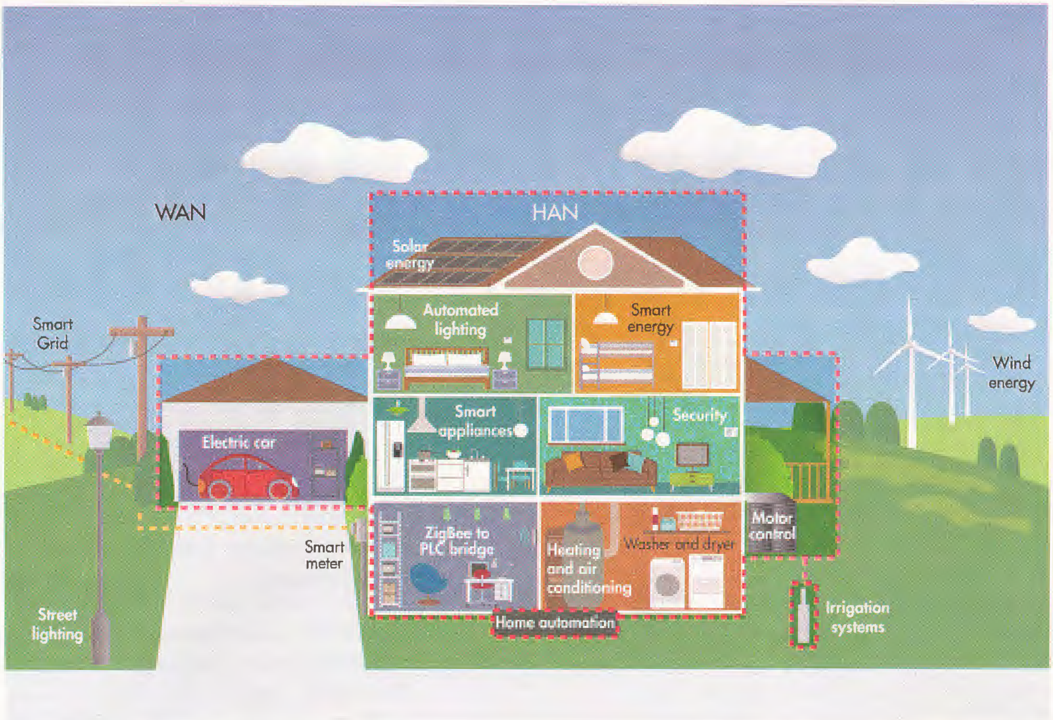
THE BROADBAND STANDARDS

Dozens of different methods and standards have been developed for PLC. The standards fall into two general categories: narrowband (NB), low-speed, long distance; and broadband (BB), high-speed, short distance.

The low-speed, long-distance standards are used in powerline metering, Smart Grid control, HANs for appliance control and security, and building monitoring and control. The high-speed standards apply to using the power line for high-speed Internet access in a HAN and for transferring video from one box to another.

By far the most widely used high-speed PLC variant is HomePlug (HP) from the HomePlug Alliance *(www.homeplug.org)*. Version 1.0 of this standard has been around since the late 1990s, and millions of HomePlug PLC products have been sold since then.

The 2.0 version, HomePlug AV (HPAV), is widely used in set-top boxes (STBs) and home Internet gateways and routers.



2. PLC is used throughout the home and Smart Grid. It can be used to measure energy from the utility and even alternative energy sources like wind farms. It is especially useful in the home where it interconnects all energy sources including solar. The HAN lets you monitor energy use and control appliances. PLC also is used in high-speed video connectivity and Internet access. *(courtesy of Texas Instruments)*

It's capable of a 200-Mbit/s gross data rate (150 Mbits/s net) across noisy home power lines.

HPAV uses OFDM in the 2- to 28-MHz range. There are 1024 subcarriers and modulation of BPSK to 1024-state quadrature amplitude modulation (1024QAM). A turbo convolutional code is used for forward error correction (FEC).

Indicating that HP is the PLC standard to beat, the IEEE recently established its PLC standard P1901.1, which is based on HPAV. HPAV uses the traditional fast Fourier transform (FFT) form of OFDM.

An advanced version of the standard called HP AV2 extends the bandwidth out to 86 MHz with more subcarriers, making it possible to achieve data rates to 500 Mbits/s and 1 Gbit/s under favorable conditions. The standard is being finalized now, and end products are expected later this year.

Panasonic developed one other high-speed specification, HD-PLC, which is used in some STBs for Internet protocol television (IPTV) service. It uses the different wavelet OFDM instead of the standard FFT version. HD-PLC is also covered under the IEEE P1901.1 standard, which specifies co-existence methods for both HD-PLC and HPAV.

The Digital Living Network Alliance (DLNA), which can be found online at *www.dlna.org*, has certified HD-PLC as a standard communication method for creating interoperable networks of PCs, TV sets, and other consumer electronic devices. More HD-PLC details are available from the HD-PLC Alliance at *www.hd-plc.org*.

Several years ago, a Spanish company named DS2 developed another high-speed standard that was established by the Universal Powerline Association (UPA). Marvell later acquired DS2, but many STBs supplied by European cable TV and Internet service providers still use the UPA standard.

Finally, there's G.hn, an international standard of the International Telecommunications Union (ITU) promoted by the HomeGrid Forum *(www.homegrid.org)*. It can be used on any wired medium including telephone-line twisted pair, coax, or power line. The physical-layer (PHY) protocol standard is G.9960, and the media access control (MAC) standard is G.9961.

G.hn was developed because of the proliferation of multiple wired networking standards for home networks, which has slowed adoption because of the consumer confusion in the marketplace as well as the lack of interoperability between different connected devices. It's the ITU's attempt to increase the potential for more widespread adoption for wired home networking.

Using OFDM, the G.hn standard can achieve data rates up to 1 Gbit/s. It supports baseband band plans with bandwidths of 25, 50, and 100 MHz. The standard is also compatible with the G.hn low-complexity profile (LCP) for low-speed devices such as Smart Grid metering and smart appliance monitoring and control.

G.hn includes various techniques for added reliability such as low-density parity check (LDPC) FEC, an automated block-level error detection and retransmission scheme, an enhanced selective repeat ARQ-based (automatic repeat request) acknowledge character (ACK) algorithm, and a special robust communications mode for high-noise environments.

The standard's automatic mesh networking provides for relaying between nodes that cannot connect directly. Security is provided by 128-bit AES CCMP encryption, end-to-end encryption, and strict authentication rules. The G.hn standard also features multiple-input multiple-output (MIMO) for added reliability.

MIMO uses two or more transmitters and receivers over separate signal paths to boost data speed and minimize multipath effects and noise. In PLC, MIMO uses two paths: the power-line "hot" wire and the neutral line. Normally, the neutral line is connected to ground. But in some cases, it can be used to provide a second signal path to increase data rate and improve reliability.

G.hn competes with multiple wired home networking technologies. In the PLC arena, HomePlug is its key competitor. Another wired competitor, the Multimedia over Coax Alliance (MoCA) standard, has been around for several years. Many cable companies have adopted MoCA for STB connectivity over the existing home coax cable TV wiring.

AT&T has adopted HomePNA for video distribution over home telephone wiring. As for ac power-line networking, the HomePlug standard dominates. Throw in the IEEE's 1901 standards, and the result is a real mix that's confusing not only to the consumer but also to the STB industry. G.hn provides for coexistence with the IEEE 1901 networks (G.cx standard).

One more confusion factor is the IEEE's P1905 standard effort to make existing home network technologies work together. This yet to be ratified standard includes Wi-Fi wireless, Ethernet, and MoCA. The goal is to create hybrid home networks that let the different networking technologies work together via an abstraction layer in the software that would permit dynamic interface selection, wired or wireless.

The standard includes features designed to make the network easier to set up and manage, benefitting consumers as well as pay TV and Internet service providers. G.hn and HomePNA are excluded from this standard, although possible future inclusion isn't ruled out.

THE NARROWBAND STANDARDS

The most common NB low-speed standards today are IEC 61334, IEEE 1901.2, HomePlug Green PHY, G3, PRIME, and G.hnem. Most use the CENELEC (European Committee for Electrotechnical Standardization) frequency bands. The CENELEC standards use the frequency spectrum from 3 to 160 kHz. There are four CENELEC bands for Europe: A, B, C, and D *(see the table)*.

Other low-speed standards can use frequencies up to 500 kHz. The FCC in the United States allows up to 490 kHz. The Association or Radio Industries and Businesses (ARIB) in Japan permits up to 450 kHz.

With such carrier frequency assignments, the possible data rates are very low, typically less than 10 kbits/s. This is not a disadvantage. In fact, it is an advantage since lower data rates deliver a lower bit error rate (BER) over a given distance with a known noise level. Most home monitoring and control including power-line meter reading is performed at low speeds, meaning that reliability and accuracy are excellent.

The IEC 61334 from the International Electrotechnical Commission is used primarily in reading electric and water meters and with the supervisory control and data acquisition (SCADA) telemetry system. It operates in the 60- to 76-kHz CENELEC A band and can have a data rate in the 1.2- to 2.8-kbit/s range.

EUROPEAN CENELEC BANDS

Band	Frequency range	Use
No band	3 to 9 kHz	Reserved for utilities
A band	9 to 95 kHz	Energy suppliers, their suppliers/licensees
B band	95 to 125 kHz	Consumer use, no protocol
C band	125 to 140 kHz	Consumer use, with protocol
D band	140 to 148.5 kHz	Consumer use, no protocol

The standard uses spread-frequency shift keying (S-FSK), which is standard FSK, but the two frequencies chosen for the binary 0 and 1 symbols must be spaced 10 kHz or more. This minimizes the possibility that some form of NB interfering signal would corrupt both symbols.

The data transmission is synchronized to the zero crossings of the power-line frequency, either 50 or 60 Hz. A zero crossing detector determines when to transmit either 24 or 48 bits per cycle, most significant bit (MSB) first.

This provides for 1200 bits/s at 50 Hz or 1440 bits/s at 60 Hz with 24 bits per cycle or 2400 bits/s at 50 Hz or 2880 bits/s at 60 Hz. The protocol forms 42-byte packets with the first 4 bytes being a preamble followed by 38 bytes of data and then 3 bytes of silence.

PRIME (PoweRline Intelligent Metering Evolution) uses the CENELEC A band from 42 to 90 kHz and can achieve data rates in the 21- to 128-kbit/s range. It uses OFDM and can support multiple nodes. The OFDM uses 97 subcarriers, one of them a pilot and the other 96 for data.

Subcarrier spacing is 488.28125 Hz. Modulation options include differential BPSK, differential quadrature phase-shift keying (QPSK), and differential eight-phase-shift keying (8PSK). OFDM is particularly robust in the presence of noise of all types and has proven to be the best PLC modulation method for higher speeds and longer ranges.

The PRIME protocol also uses convolutional coding for FEC and a cyclic redundancy check (CRC), making the transmission quite reliable with low BER. Both MAC and PHY standards are fully defined. PRIME also uses a carrier sense multiple access with the collision avoidance (CSMA/CA) access method.

Developed by Electricite Reseau Distribution France (ERDF) for automated electric meter management, the G3-PLC standard also is a low-frequency NB standard using OFDM. Different versions are available to operate in any of the CENELEC, FCC, or ARIB bands at data rates up to 46 kbits/s in the CENELEC bands and up to 141 kbits/s in the FCC and ARIB bands.

The modulation is OFDM using differential binary phase-shift keying (DBPSK), differential quadrature phase-shift keying (DQPSK), or eight-ary differential phase-shift keying (D8PSK). A typical format is 36 subcarriers and a normal 33.4-kbit/s data rate. As many as 128 subcarriers can be selected.

The system uses Reed Solomon and convolutional coding for FEC. A Robust mode repeats each bit four times to improve transmission reliability. Other features include AES-128 encryption and the ability to use point-to-point, star, or mesh topologies. The standard supports IPv6. Access is via CSMA/CA. The MAC layer is similar to the IEEE's 802.15.4 wireless standard, which includes ZigBee.

The IEEE P1901.2 is another low-frequency NB standard.

NEW PRODUCTS JUMP ON THE PLC BANDWAGON

POWER-LINE COMMUNICATIONS (PLC) is becoming a key communications technology. Thanks to new standards and a flood of new chips and products, PLC is finding a place in home area networks (HANs), in the Smart Grid, and in industry.

Sending data over the existing ac power lines is an old and good idea that has been chronically plagued by noise and high attenuation problems. Today, new technology—specifically orthogonal frequency division multiplexing (OFDM)—has made PLC reliable over longer distances and incredibly useful. It is even replacing wireless in some high-speed video applications in consumer electronics equipment.

The PLC marketplace is divided between broadband (BB) high-speed short-range applications and the narrowband (NB) low-speed longer-range applications. The HomePlug specification and related IEEE P1901.1 standard dominates the BB arena, but the newer ITU standard G.hn is poised for growth.

In the NB sector, the G3 standard and its IEEE cousin P.1901.2 are doing well, but multiple other standards are finding their place in the Smart Grid and HANs. With plenty of new silicon now available, it won't be long before you see some new and interesting PLC products.

Lantiq's XWAY HNX100 G.hn networking transceiver includes a fully ITU G.9960/G.9961-compliant media access controller (MAC) and physical layer (PHY). It supports transmissions over power line, coax, and twisted pair. Also, its OFDM band plans can support data rates to 1 Gbit/s.

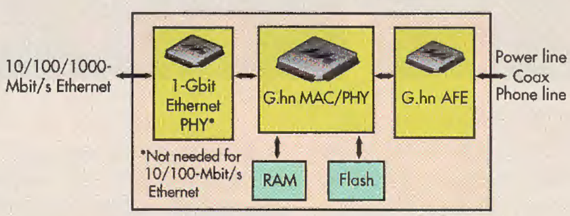
The integrated serializer-deserializer (SERDES) interface lets the device connect to different analog front ends (AFEs). The transceiver incorporates a MIPS processor for the software and can use a wide range of available operating systems. The HNX156 is designed for cost-effective systems that don't require external double-data rate (DDR) memory. The HNX176 supports DDR1/2 memory for larger, more sophisticated systems.

Freescale Semiconductor's 56F8000 DSPs can be used to implement space frequency-shift keying (S-FSK) modems or any flavor of OFDM modem. These devices target smart metering applications. They're used in the modem back to the utility and in concentrator designs. Freescale recommends its ZigBee wireless solutions for the home-area network (HAN).

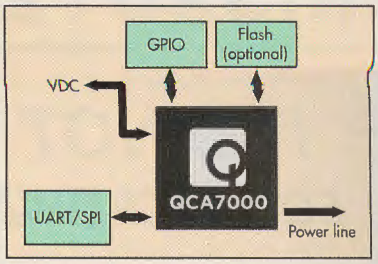
Marvell's ITU-T G.hn-compliant transceiver chipset accommodates all three existing home wiring network media: ac power line, telephone wiring, and cable TV coax. It appears to be an ideal solution for the wired distribution of bandwidth-intensive and real-time applications such as HD Internet Protocol television (IPTV), Voice over Internet Protocol (VoIP), gaming, multi-room DVR, and video surveillance. It has the potential to deliver a theoretical data rate up to 1 Gbit/s with an expected realistic data rate in the 200- to 400-Mbit/s range.

Marvell's G.hn chipset comprises the 88LX3142 digital baseband processor and the 88LX2718 AFE interface. The 88LX3142 includes a powerful CPU and a full set of serial interfaces, while the 88LX2718 AFE includes two fully programmable receiving and transmitting paths that enable multiple-input multiple-output (MIMO) operation.

While MIMO is generally considered a wireless technology, it nevertheless works well over a wired medium where multiple streams of parallel data boost the data rate while providing a more reliable connection in the presence of noise and interference. The 88LX3142 fully complies with the ITU-T G.hn standards, including G.9960/61/72 on any wire line like coax, twisted pair, or ac power-line *(Fig. 1)*.



1. G.hn gateways and routers can use the Marvell 88LX3124 G.hn baseband digital processor (center) and the 88LX2718 AFE (right) with an Ethernet interface to the PC or TV STB.



2. The Qualcomm Atheros QCA7000 makes a simplified solution, integrating all of the components needed for a PLC modem including the AFE, power management unit, and RAM and ROM. UART and SPI interfaces are provided as well. It comes in a 68-pin, 8- by 8-mm quad flat no-lead (QFN) package.

The 88LX2718 is all a user needs to accommodate the signal between the 88LX3124 G.hn baseband digital processor and the coax, phone-line, or power-line line transformer. It integrates all circuitry—amplifiers, active filters, line drivers—required for this function.

The AFE is built upon two transmission/reception paths to enable true MIMO operations. Each transmission path integrates a low-pass filter, a programmable gain amplifier (PGA), and a line driver to condition the OFDM signal provided by the 88LX3142 circuit to the coax, phone, or power-line transformer. The output of the transmission path directly drives the line transformer input through an external decoupling capacitor.

Maxim Integrated Products offers a G3-PLC chipset that's widely used in Europe. It complies with the International Telecommunications Union (ITU) standards. The MAX2992 modem combines the PHY and the MAC layer. It uses OFDM with binary phase-shift keying (BPSK), quadrature phase-shift keying (QPSK), and eight-phase-shift keying (8PSK) modulation. The modulation is fully adaptive to noise and attenuation levels. The maximum data rate is 300 kbits/s.

The modem uses the 6LoPAN ITEF standard to support IPv6. Both dynamic routing and mesh networking are supported. Access is CSMA

It is based upon the G3-PLC standard and uses OFDM in any of the bands from 10 to 490 kHz. Modulation can be DBPSK, DQPSK, or D8PSK. Data rates vary by application but are less and ARQ to improve reliability. Forward error correction (FEC) and CRC16 are used to further improve transmission reliability. AES128 provides security. The MAX2992 includes Maxim's MAXQ 32-bit microcontroller. Interfaces are two standard universal asynchronous receiver-transmitters (UARTs) and two serial peripheral interfaces (SPIs).

The MAX2991 AFE chip interfaces to the ac line. The receive path includes a filter, a variable gain amplifier (VGA), and a 10-bit analog-to-digital converter (ADC). The chip also features a 62-dB dynamic range automatic gain control (AGC) and dc offset cancellation. The transmit path includes a 10-bit digital-to-analog converter (DAC) and a shaping filter. Its programmable filters comply with the CENELEC, Federal Communications Commission (FCC), and Association of Radio Industries and Businesses (ARIB) band limits.

Qualcomm Atheros, which entered the PLC marketplace with its acquisition of PLC pioneer Intellon, makes a full range of HomePlug-related products. For example, its INT6400 is a full MAC and PHY for HomePlug AV capable of the 200-Mbit/s speed defined by the specification. The INT1400 is the matching line driver IC and AFE. It includes an Ethernet Media Independent Interface (MII) and works with external SDRAM.

The company's AR7400 MAC and PHY chip and the matching AR1500 line driver/AFE fully comply with the HomePlug AV specification and the IEEE P1901 standard. This chipset extends the OFDM band plan from 2 MHz out to 86 MHz, providing data speeds up to 500 Mbits/s. Primary applications include set-top boxes (STBs) and video streaming. The smaller AR7420 offers similar specifications and is available with the AR1540 companion line driver IC.

The Qualcomm Atheros QCA7000 IC is another solution designed for HANs *(Fig. 2)*. Target devices include smart meters, home energy management systems, appliances, and electric vehicle charging stations. The IC is based on the new HomePlug Green PHY standard from the HomePlug Alliance.

The QCA7000 is single-chip device with an integrated power management unit, AFE, and memory in a tiny 8- by 8-mm package. A single 3.3-V rail powers it to allow for reduced system cost and easy integration into customer designs.

To support embedded applications, SPI and UART host interfaces are available on the chip to allow direct connectivity to low-cost, low-power microcontrollers commonly found in the smart energy ecosystem. A general-purpose I/O (GPIO) bus and an optional flash interface are available to support simple applications like smart plugs and sensor monitors.

Sigma Designs offers a variety of chips, but the company's most flexible product is the CG5110. This complete G.hn modem complies with G.9960/8861/9962. It's also backward compatible with HomePlug AV, P1901.1, and Home PNA standards, providing a way for service providers to transition smoothly from the older legacy solutions to G.hn. ■

than 500 kbits/s. It's designed to operate between an electric meter and the transformer (<1 kV), but it also works through an LV to MV transformer (1 up to 72 kV).

P1901.2's range is many kilometers. Access is by way of CSMA/CA, and IPv6 is supported. P1901.2 also leverages the IEEE 802.15.4 wireless MAC. Reed Solomon and convolutional codes plus Robust (repeat) modes are used for FEC and greater reliability.

One of the oldest standards for PLC is from Echelon. Founded in the 1980s, Echelon makes chips that work in the CENELEC A and C bands. The A band transceivers operate with carriers of 75 and 86 kHz, while the C band devices use carriers of 115 kHz and 132 kHz. If an interferer blocks a channel, the device automatically switches channels.

The modulation is BPSK, and the receiver uses DSP noise cancellation and distortion correction to improve reliable reception. FEC and CRC are used to further improve performance in noise environments. Echelon's LonWorks software implements networks for street lighting control, building automation, and meter reading.

HomePlug Green PHY is another narrowband option. It is interoperable with the IEEE P1901/HomePlug AV power-line networking protocols. HomePlug Green PHY is designed for lower-speed applications with data rates to 10 Mbits/s but with 80% less power consumption.

The HomePlug Green PHY (HPGP) uses the same OFDM modulation scheme as HomePlug AV but offers features that better fit the needs of a HAN. HPGP is IP-based technology that handles IP protocols, such as ZigBee's smart energy profile (SEP) 2.0, without translation layers. IT also can natively support MAC layer bridging to Wi-Fi, Ethernet, and cellular technologies.

Another emerging standard, G.hnem, is a variant of the G.hn standard. It is a simplified form of G.hn for use in low-speed applications, especially energy management and home networking for monitoring and control. G.hnem uses the CENELEC and FCC bands to 500 kHz and is good for data rates to 1 Mbit/s.

G.hnem's modulation is OFDM with either 128 or 256 subcarriers with 1.5625- or 3.125-kHz spacing with 16-phase QAM (16QAM). The ITU standard designations are G.9955 (PHY) and G.9956 (DLL). Targeted applications include smart meters, energy management, electric vehicle communications and charging, and home automation.

THE APPLICATIONS

Many applications use PLC, and adoption is increasing as devices are improved. For example, the Smart Grid uses computers and intelligence for improved monitoring and control of the world's ac power transmission and distribution networks. This requires communications, and PLC is a logical choice.

PLC also is widely used to read electric, water, and gas meters remotely. It is a natural for electrical utilities. Meter readings are sent to a neighborhood collection point and then forwarded to the utility for billing purposes. The meter readings and power consumption data is also made available to the consumer's HAN for use in better energy savings.

As more homes implement HANs, PLC makes it is easy to provide energy management and control as well as control the related heating and air conditioning systems. It is also possible to control appliances equipped with the necessary interfaces to allow status monitoring, timing, and/or on/off control.

Home and building security systems can use PLC for sensor monitoring, video surveillance, and related control functions. Also, PLC can be used to monitor temperature and other environmental conditions, lighting control, HVAC control, and security. PLC is widely used for streetlight monitoring and control as well.

PLC is even fast enough to provide home and/or office coverage for high-speed Internet access. Consumers now widely use HANs using Wi-Fi wireless as newer PLC systems can deliver high speeds for video distribution from the STB to TV or DVR or DVD to TV or other combination for video streaming. Room-to-room distribution is also possible with the faster PLC systems.

IN SUMMARY

With so many standards for both BB and NB PLC, it is a difficult decision for both industrial users and consumers. In the BB sector, HomePlug dominates but G.hn products are emerging now that silicon is available. Many new G.hn chips will find their way into STBs and Internet gateways and routers. It will be interesting to see if G.hn can capture some of the market share now owned by HomePlug.

In the NB sector, there are even more options. It has been difficult to determine overall market share as the market is so scattered around the world. It appears that the G3-PLC standard has the most momentum right now. P1901.2 is the answer, as it supports G3 and PRIME as well as G.hnem.

But since PLC used by utilities does not have to have worldwide interoperability, each utility can chose any standard for meter reading and other Smart Grid functions. It is obviously a useful option to choose the best technology for the existing environment, grid topology, or noise conditions.

Regardless of which standards will win, overall PLC has become a solid communications technology that will find its way into more products. It will certainly be one of the technologies deployed in the forthcoming Internet of Things (IoT). ed

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