

Don Shaver,  
TI Fellow  
Smart Grid Business Unit  
Texas Instruments

## Introduction

Texas Instruments (TI) leading power line communications (PLC) technology has enabled Cygnus Electronics to create a PLC hardware and software platform designed for automotive qualification in electric vehicles. Auto-rem implements the Society of Automotive Engineers' (SAE) J2931-3 specification, which is a narrowband orthogonal frequency division multiplexing (OFDM) proposal for plug-in electric vehicle (PEV) to electric vehicle service equipment (EVSE) communications during PEV battery charging<sup>[1]</sup>. J2931-3 is based on the upcoming IEEE P1901.2 international narrowband OFDM standard. The auto-rem system uses a TI PLC chipset comprised of an optimized OFDM C2000™ Piccolo™ microcontroller (TMS320F28069)<sup>[2]</sup> and an integrated analog front end AFE031<sup>[3]</sup>, which integrates more than 100 discrete devices. PLCSuite™<sup>[4]</sup> is a certified communications and networking software library that puts power into the hands of Tier-1, Tier-2 and other developers to achieve fast time-to-market and the ability to add their own unique differentiation. Auto-rem and its components bring cost performance to new levels, while achieving flexibility and scalability to address future industry needs.

# TI helps developers design affordable, robust and high-performance communications between plug-in electric vehicles (PEVs) and electric vehicle supply equipment (EVSE)

## J2931-3 narrowband OFDM for PEV to EVSE communications

The SAE J2931-3 specification is based on IEEE P1901.2, a future international communications standard. Standards enable the development of competitive and interoperable chipset solutions, which fuel the market as competitive pricing takes hold and chipset volumes increase. Profiles from the IEEE P1901.2 standard were selected and organized into a formal SAE technical proposal/specification in January 2011 for consideration by the SAE PEV committee. A J2931-3-compliant modem communicates between the PEV and EVSE over existing wires of the PEV charging cable, such as SAE J1772™-compliant cables. The frequency band plan for J2931-3 includes subsets within the 3-KHz to 500-KHz band. The frequency bands used at any locality depend on country-specific regulations (e.g., Cenelec (Figure 2), FCC<sup>[7]</sup>, ARIB).

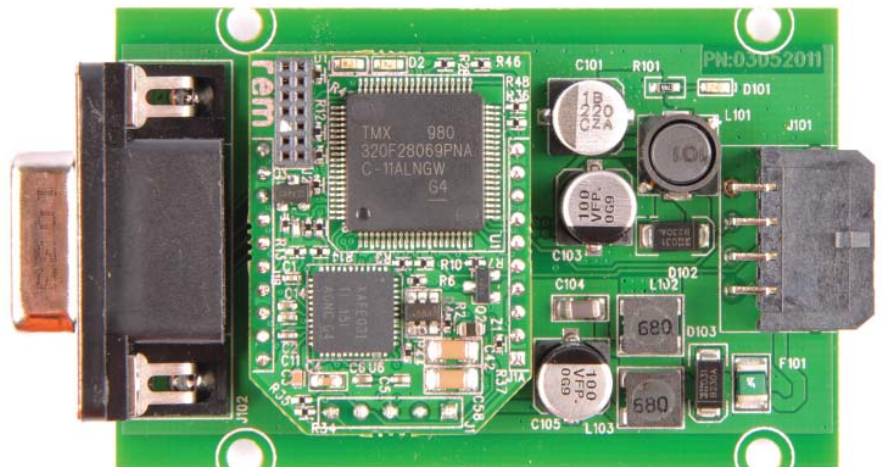


Figure 1. Cygnus “auto-rem” reference design and chipset are designed for automotive qualification and can be used almost immediately in PEVs.

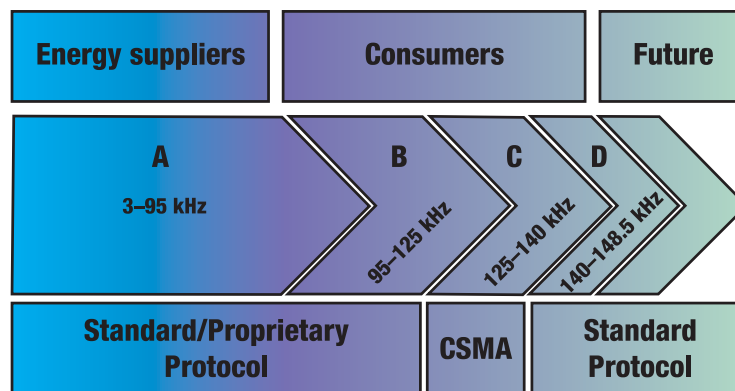


Figure 2. Cenelec PLC regulations in Europe.

### Communications over the J1772 PEV charging cable<sup>[6]</sup>

The SAE J1772 charging cable incorporates five conductors: two for AC or DC power (AC/DC mains), one for proximity detection, one for the pilot control signal and one for equipment ground. The control pilot carries a  $\pm 12\text{V}$  PWM signal to provide information to the PEV such as charging level. The challenge addressed by the J1772 standard is to develop a modem that can communicate reliably between the PEV and the external car charger EVSE without adding new wires. Adding new wires increases the cable cost, reduces reliability and makes it more difficult to handle the cable and repair it. Two approaches are being considered:

1. Communications over the AC/DC mains
2. Communications using the control pilot/equipment ground

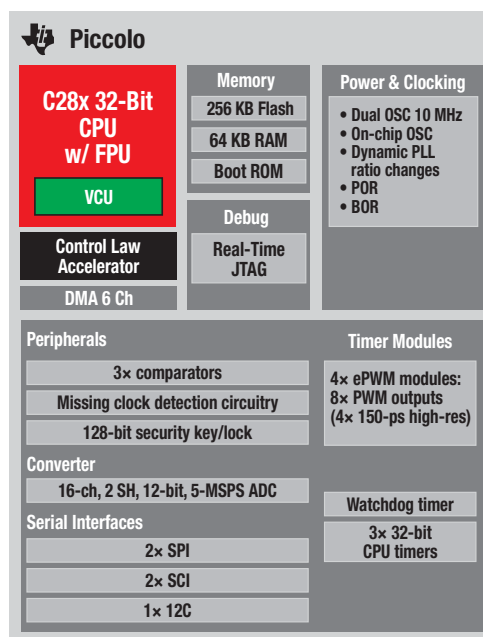
The auto-rem solution supports both types of communications; however, in the near-term TI is focusing on control pilot communications. The advantages of pilot wire communications compared to communication over the mains include:

1. A more benign environment exists on the control pilot, making it easier to communicate reliably and at higher bit rates.
2. The usable bandwidth is not as restricted in certain countries. For example, for PLC in European countries, PEV communications is currently limited to the Cenelec B, C and D band frequencies between 95 KHz and 148.5 KHz (53.5 KHz bandwidth). In contrast, in Europe, the full bandwidth between 3 KHz and 500 KHz (491 KHz bandwidth) can be exploited using the control pilot wire. This could result in nearly 10 $\times$  the bit rate performance compared to using the mains.

As a caveat, the  $\pm 12\text{V}$  pilot signal integrity including pulse widths must be maintained per the J1772 specification. The modem to control pilot wire coupling circuit design is important in achieving the required modem bit rate while not distorting the PWM signal outside its limits. The maximum modem signal on the pilot wire must be below 500mV peak-to-peak to maintain PWM signal integrity. The J2931-3 technology provides a power control mechanism to ensure the signal on the pilot line is below 500 mV.

### OFDM MCU and AFE031 front end implement J2931-3

The heart of any PLC system is the analog front end, including line-coupling circuits and the digital modem and network processor. The modem processor performs the signal processing including modulation/demodulation, medium access control (MAC) and network layer processing such as routing, IPv6 and applications processing. The processor memory and processing power dictate the amount of signal bandwidth that can be processed and the achievable data rate. To minimize cost while increasing performance, TI has enhanced the instruction set of its C2000 platform of microcontrollers with instructions that accelerate OFDM modem signal processing and networking functions. The TMS320F28069 Piccolo<sup>[2]</sup> OFDM microcontroller is shown in Figure 3. The new instructions are implemented by the Viterbi Complex Math Unit (VCU), a tightly coupled coprocessor. The VCU includes operations that accelerate modem PHY and MAC processing functions.

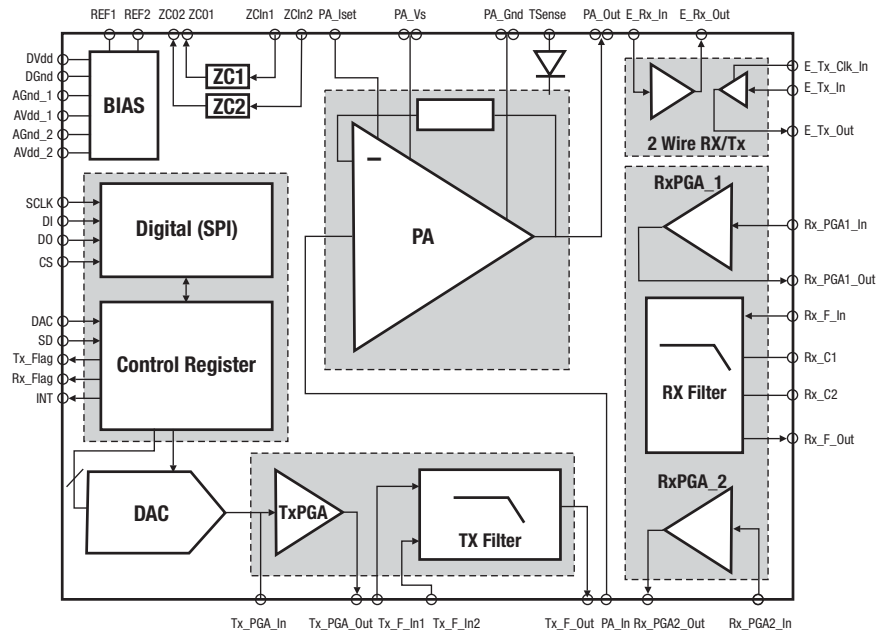


**Figure 3. Application-specific OFDM MCU achieves high performance simultaneously with low power and low cost.**

Of course, if no modem signal is present at the microcontroller analog-to-digital converter (ADC), there's not much the MCU can do to extract the transmitted modem waveform. The role of the high-performance, integrated analog front end (AFE031) (see Figure 4 on the following page) is to filter, condition, amplify/receive the signal and couple the modem system to transmission line. TI has decades of successful products and experience in its precision analog products business. This experience was fully utilized in the AFE031 design.

### Modem emissions

Emissions are classified as conductive or radio frequency (RF), and there are emissions limits defined by the FCC in the U.S. and vehicle manufacturers have even more stringent emissions requirements. Emissions limits are defined by Cenelec in Europe, ARIB in Japan and other countries have specified emissions limits. Emissions can potentially interfere with other car systems, like the radio, or emissions can affect systems



**Figure 4. Integrated analog front end combines over 100 discrete devices for best-in-class cost/performance.**

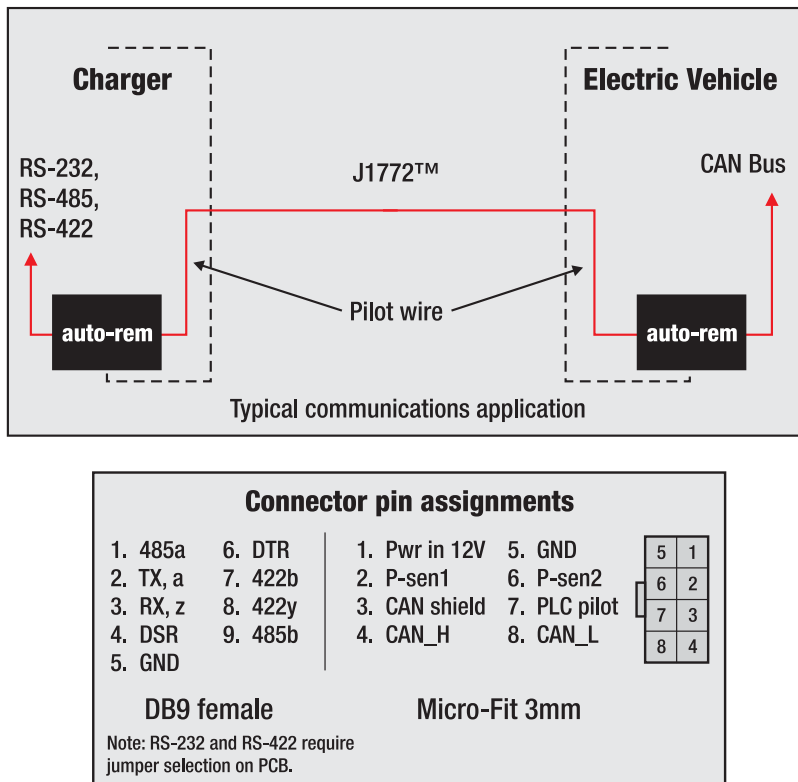
outside the car. For example, Ham radios, some aeronautical and shipboard radios and some radar systems (OTH<sup>[8]</sup>) operate in high-frequency (HF) bands (3 to 30 MHz). However, narrowband OFDM modems like J2931-3 operate below 500 KHz, so there is no possibility of interfering with these external communications and radar systems.

Another emissions concern is associated with multiple, closely-spaced charging stations (EVSEs), such as in parking garages or in apartment complexes. The concern is that adjacent charging stations can “hear” each other via emissions and then get confused about whose plug-in electric vehicle is attached to it. The narrowband OFDM solution has been shown to not have this problem, but in a recent U.S. Department of Energy-funded testing report<sup>[9]</sup>, it was shown that one EVSE operating in the HF band can be heard by an adjacent EVSE in close proximity.

### ***Tunneling automotive busses over power lines via auto-rem***

Another benefit of using TI's chipset is the support for automotive bus interfaces such as the controller area network (CAN). The OFDM microcontroller includes a CAN<sup>[10]</sup> bus interface/controller and there are several CAN busses and DC power available throughout the vehicle. Now the flexibility exists to transparently communicate between a pair of CAN endpoints (e.g., in a battery management system) over existing DC power wires using auto-rem.

A modern automobile may have as many as 100 electronic control units (ECUs) for various subsystems. ECUs require power, which is provided via the vehicle's DC power cables. ECUs include the engine control unit and others such as for the transmission, airbags, anti-lock braking system (ABS), cruise control and electrical steering. Communication among many of the ECUs is essential while in some cases ECUs may operate independently. The CAN standard fulfills many of these communication needs. But now, PLC coupled



**Figure 5.** CAN bus tunneling over power line or pilot wire creates new opportunities to dramatically reduce wires in cars.

with CAN could emerge as an important application for auto-rem designs in the future, in addition to the PEV-EVSE application (Figure 5).

## Summary

The Cygnus Electronics auto-rem reference design, coupled with TI's automotive-qualified digital and analog ICs, allow customers to achieve fast time-to-market with a J1772 charging cable solution along with the capability to add differentiation. TI's certified PLCSuite™ software with multi-layer APIs gives customers the opportunity to develop their own modems or higher layer software on top of the TI PLC library software.

The J2931-3 specification provides PLC technology in frequencies below 500 KHz for low emissions, meets country-specific regulations and achieves high bit rates at the same time. Eliminating the need for new wires in charging cables improves reliability and reduces cable costs. The J2931-3 technology can be used to communicate over the charging cable AC/DC mains or via the control pilot conductor.

Beyond the PEV to EVSE communications application, there are other uses of auto-rem in vehicles such as tunneling CAN information transparently over the vehicle's DC power lines without requiring new wires.

Finally, the TMS320F28069 Piccolo OFDM microcontroller is 100 percent software programmable. As communications standards evolve, the implementations can evolve in parallel without the need of using completely new ICs.

For more information, please visit [www.ti.com/auto-rem](http://www.ti.com/auto-rem)

**References**

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