Inductive Coupling Characteristics of Nano-crystalline Alloy for Electric Vehicle PLC

Kyung-Rak Sohn, Seung-Ho Yang, and Jae-Hwan Jeong
Dept. of Electronics and Communications Engineering, Korea Maritime and Ocean University
727 Taejong-Ro, Yeongdo-Gu, Busan 49112, Korea
krsohn@kmou.ac.kr

Abstract**—**In this paper, we presents the characteristics of an inductive coupling unit (ICU) made of a nano-crystalline alloy for contactless electric vehicle power line communication (EV PLC). An ICU contains a toroidal transformer consisting of a circular nano-crystalline core and two wires sharing a magnetic field caused by an electric signal. An average channel bandwidth of 48 Mbps was measured when the proposed ICUs were installed on the high power line between EV and EV charger. EV PLC using a miniaturized nano-crystalline ICU will contribute to simplification and weight reduction of electric vehicle wiring.

Keywords—Inductive coupling; nano-crystalline; powerline communication; soft magnetic materials

I. INTRODUCTION

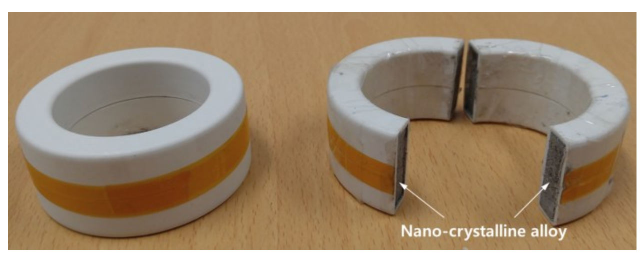
Home and outdoor powerline communications (PLCs) have attracted great interest in the possibility of broadband Internet and high-speed services without new wires. But in-vehicle PLCs, including in-car, in-ship and in-plane, are not yet in-depth research. Recently, with the introduction of electric vehicles, various types of electronic devices such as electronic control devices, sensors and actuators can be applied to automotive PLCs. Many studies have been actively carried out due to the benefits gained from the application of power line communication to automobiles [1-3]. The main advantage is that the existing wiring infrastructure can be used to simplify the design of in-vehicle data networks and reduce the weight and cost of wiring harnesses [4].

In general, PLCs have two types of coupling circuits: capacitive and inductive [5]. The former shows the required high-pass filtering characteristics. The signal power is coupled through the displacement current by the capacitor. Conventional narrow-band PLC is two-wire system that use capacitive couplers to inject signals between wires. It is compact, but it must be in physical contact with the power cable. In the latter method, the signal power is coupled to the power line in a noncontact manner by electromagnetic induction. Until recently, this is achieved by using ferrite cores for high frequencies made of soft magnetic materials. The main advantage is that the coupling circuit provides isolation from the supply voltage to the signal source without electrical contact and is simple to install on the cable.

Nano-crystalline alloys are a kind of soft magnetic material and can replace power ferrite and amorphous materials in high frequency applications of electronic devices [6,7]. In this study, we investigated the performance of inductive power line communication using a nano-crystalline alloy with saturation magnetic flux density three times higher than that of ferrite. A toroidal core type inductive coupler was fabricated and PLC test was performed between EV and EV charger.

II. NANO-CRYSTALLINE INDUCTIVE COUPING UNIT

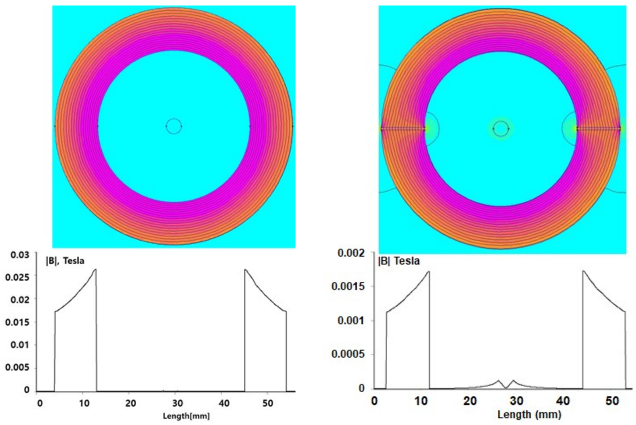
Nano-crystalline alloys are the result of making crystal grains of tens of nanometres by applying amorphous manufacturing technology. Amorphous state refer to that atoms inside the material do not have a regular arrangement. However, when the metal melts and the internal atoms are activated and the temperature decreases, the atoms return to their original, regular crystalline state. Eventually this becomes a crystalline metal. However, if the atoms are cooled too quickly to return to a regular state, they become amorphous alloys. Toroidal nano-crystalline alloy as shown in Figure 1 (a) is of the composition $Fe_{73\text{-}74}Cu_{0.8\text{-}1.2}Nb_{3.2\text{-}4.0}Si_{12\text{-}13}B_{6.5\text{-}7}$ with a saturation flux density of B_s=1.2 T and an initial permeability of μ_i=20,000-120,000 @10kHz. Typically soft ferrite has a saturation flux density of 0.5 T and an initial permeability of μ_i=5000~12000 @10kHz. The coupler consists of two half cores made by symmetrically separating one toroidal core for easy installation on existing powerlines as shown in Figure 1 (b).



(a) (b)

Fig. 1. The shape of nano-crystalline cores. (a) Toroidal core and (b) cut core.

Numerical methods provide a better understanding of the electromagnetic behavior of magnetic cores. In this study, a finite element method program FEMM 4.1 was performed to visually represent the internal flux density of the cores. Figure 2 shows the magnetic flux density distribution as the current of 1A passes through the center of the cores. In the toroidal core of Figure 2 (a), the flux is confined within the core due to their high relative permeability values when compared to other elements of the domain. However, the nano-crystalline toroidal core must be cut to join the already installed power line as shown in Figure 1 (b). In the cut core, magnetic flux leaks through the cut section as shown in Figure 2 (b).



(a) (b)

Fig. 2. Field intensity simulated by FEMM. (a) Toroidal and (b) cut core (air gap=500μm).

Figure 3 shows the magnitude of S_{21} as a function of frequency for two cores. The cut core has an insertion loss of more than 10 dB due to leakage of magnetic flux through the cut section, but the 3 dB bandwidth reaches 50 MHz from 10 to 60 MHz. At less than 10 MHz frequency range, the signal coupling efficiency by the cut cores is very low, but the low frequency noise from the power line can be easily blocked. Thus, a cut-core inductive coupling unit can be used to implement PLC systems that are insensitive to low-frequency noise.

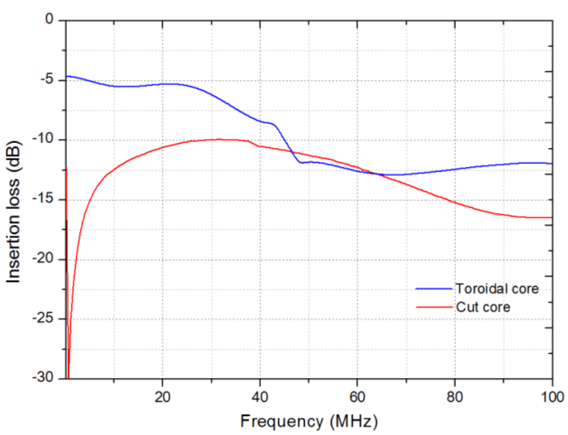
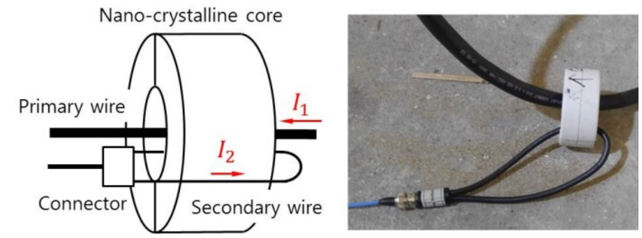


Fig. 3. Magnitude of S_{21} as a function of frequency for two cores.

An ICU contains a toroidal transformer consisting of a circular nano-crystalline core and two wires sharing a magnetic field as shown in Figure 4. By applying modulated signal to one winding, a current proportional to the coupling coefficient will be induced in the other winding. The nano-crystalline cores serve to couple the modulated signal from one winding to the other.



(a) (b)

Fig. 4. Nano-crystalline inductive coupling unit using cut-core. (a) Basic structure and (b) implementation.

III. Experimental Results and Discussion

Figure 5 shows the EV PLC measurement scheme. One of the pair of couplers is fastened to the power line of the EV charger and the other is installed on the high voltage line inside the EV. Each coupling unit is connected to a PLC modem and a monitoring PC running iperf, which is a widely used tool for network performance measurement and tuning.

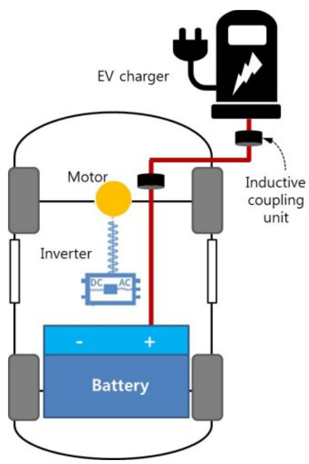


Fig. 5. Measurement scheme for EV PLC

(a) Electric vehicle (b) EV charger

Fig. 6. Experimental configurations

Figure 6 shows the inductive coupler installed inside the electric vehicle and on the EV charging cable. Cut cores were used for easy installation on existing cables.

Screenshot of iperf PC monitoring program showing the channel bandwidth are shown in Figure 7. The average bandwidth measured for 30 seconds during EV charging was 48 Mbps. There was no change in the bandwidth that could be observed even if it was not EV charging. Experimental results show that it is possible to apply EVs to inductive PLC using nano-crystalline coupling units.

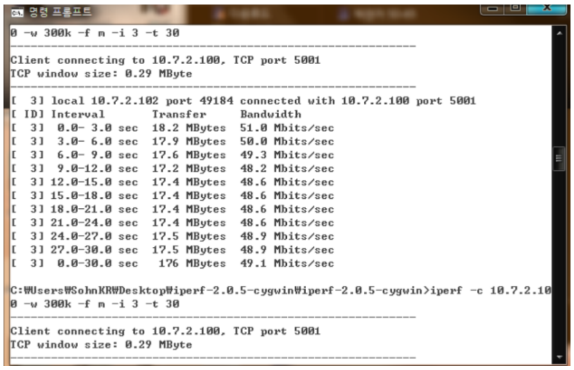


Fig. 7. Screenshot of iperf PC monitoring program showing channel bandwidth.

IV. Conclusion

In this study, we have demonstrated the nano-crystalline coupling unit for EV PLC application. For the toroidal and D-shaped nano-crystalline cores, the magnetic energy distribution for the primary current was analyzed using FEMM. The insertion loss of the cut core is as large as -10 dB or more, but it is advantageous to remove the noise by showing the filter characteristics that can block signals in the low frequency range. The proposed PLC system is expected to be applicable to the high-speed PLC in EVs because the channel bandwidth of 48 Mbp or more is obtained by using an inductive coupler made of cut cores. In addition, inductive PLC is a near-field communication that can be applied without modification of wiring in the automobile. Therefore, the nano-crystalline ICU is expected to be useful for simplifying and lightening the EV wiring harness.

Acknowledgment

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