Performance of Nano-crystalline Inductive Couplers Applied to Ship Powerline Communication

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Abstract. We have proposed a nano-crystalline inductive coupler that can arbitrarily add or move communication facilities in the ship without physical power line contact. Using a nano-crystalline inductive powerline communication system, we have achieved data rates of more than 12 Mbps between two separate cabins in the training-ship and succeeded in transmitting images on the same powerline condition.

Keywords: Nano-crystalline · Ferrite · Powerline communications
Inductive coupler · Capacitive coupler

1 Introduction

The development of power line communication technology has been concentrated on indoor applications of residential buildings, but research on industrial applications is getting less attention. However, inductive powerline communication (PLC) can be used as communication means for various industrial applications [1]. There have been studies to apply inductive PLC to ships [2] and trains [3] using ferrite cores.

Two types of coupling circuits are common, either capacitive or inductive. It should provide the necessary galvanic isolation of the PLC system from the power cable. The capacitive coupling shows the required high-pass filtering characteristics. The signal power is coupled through the displacement current by the capacitor. Conventional narrow-band PLCs are two-wire systems that inject signals between wires using capacitive couplers. It's easy and compact, but requires physical contact with the power cable. In the case of inductive coupling, the signal power is coupled to the power line in a noncontact manner by electromagnetic induction. The main advantage is that the coupling circuit provides isolation from the power source voltage to the signal source without electrical contact and is simple to install and remove [4].

Two representative core materials for inductive coupling unit (ICU) are ferrites and nano-crystalline magnetic materials. Ferrites are ceramic-like materials with a typical saturation flux density about 0.38 T for high permeability materials of about 10,000. Nano-crystalline magnetic materials are metallic materials with a typical saturation flux density of 1.2 T. Their permeability can be tightly controlled between 20,000 and

© Springer Nature Singapore Pte Ltd. 2019
S. O. Hwang et al. (Eds.): ICGHIT 2018, LNEE 502, pp. 31–36, 2019.
https://doi.org/10.1007/978-981-13-0311-1_6

100,000. These two parameters, saturation flux density and permeability, affect the size and performance of the couplers [5]. For instance nano-crystalline materials allow manufactures to build inductive couplers, which require magnetic cores up to several times smaller than similar cores made of ferrites [6].

In this study, we investigated the performance of an induction type PLC which can add communication equipment without changing the existing power distribution network in a ship. It is discussed how the magnetic characteristics of the toroidal core affect the coupling efficiency of the ICUs. From the computational simulation using the FEMM, it has been verified that the magnetic flux density of the nano-crystalline core is much higher than that of the ferrite. The relation between magnetic flux density and data transmission capacity was investigated. The nano-crystalline inductive PLC system showed better channel connectivity than the ferrite cores.

2 Experimental Results

Figure 1 shows the shape of the ferrite and nano-crystalline cores. Ferrites exhibit various properties depending on the kind and composition ratio of metal ions such as Fe, Mn, Ni, Mg, Zn, Cu, and Co. The basic structure of the magnetic inductor unit, first proposed by Mitsubishi Electric in 2005, is now one of the most important components in power electronic devices and is implemented as a high frequency filters, magnetic energy storages, EMC chokes, magnetic fault current limiters, etc. [7].

Fig. 1. The shape of toroidal cores. Ferrite core (left) and nano-crystalline core (right)

The first nono-composite soft magnetic alloy based on the Fe-Cu-M-Si-B alloy was obtained by Yoshizawa et al. [8]. A 20 mm thick ribbon was made of amorphous metal and rolled into a toroidal core. And then the core materials were annealed to produce the nano-crystalline magnetic material with an average grain size of 10 nm.

Figure 2 shows the frequency coupling characteristics for the three material cores. Nano-crystalline shows higher coupling efficiency in the operating frequency range than two ferrites. Mg-Zn ferrite is effective for blocking noise in the low frequency region of kHz. The upper limit frequencies are around 30 MHz and the insertion loss of

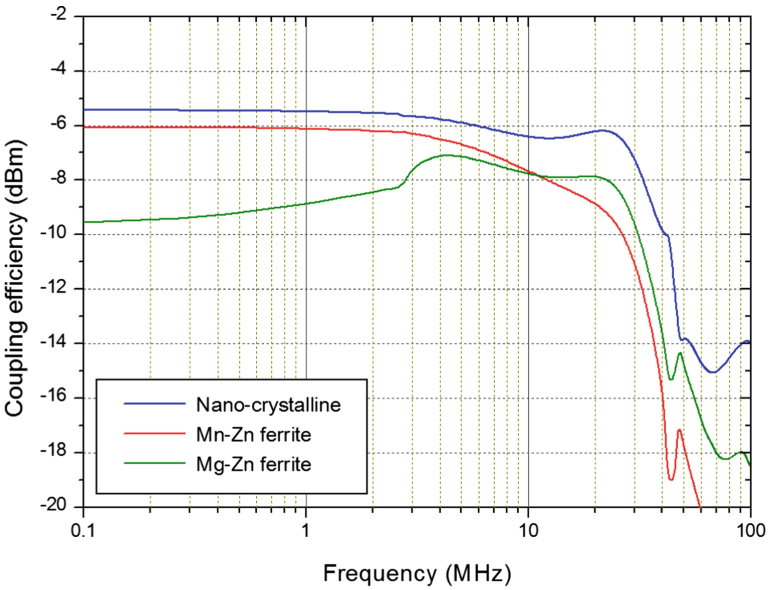

Fig. 2. Coupling efficiency for the different cores

the passband is about −5 dB on the average. The bandwidth almost coincides with the HD- PLC frequencies.

The ICUs contain a circular transformer consisting of magnetic cores and two wires sharing a magnetic field. By applying modulated signal to a primary winding, a current proportional to the coupling coefficient will be induced in a secondary winding. Therefore the core serves to couple the modulated signal from the primary winding to the secondary winding or vice versa. When the current (I) flows through the center of toroidal cores clamped over the powerline, the magnetic energy (W) accumulated in the core is expressed by Eq. (1).

$$\mathrm{W} = V_{core}\int_0^B H\,dB = \frac{1}{2}V_{core}\frac{B^2}{\mu} == \frac{V_e}{2}\mu_e\mu_0\left(\frac{N}{l_e}I\right)^2 \tag{1}$$

where B, V_{core}, µ, and l_e represent flux density, volume, permeability of the core, and magnetic path length, respectively. From Eq. (1), the size of the core and the kind of material are determined according to the magnitude of the current flowing in the power line.

To demonstrate the communication capacity of the distribution cable inside the vessel, an inductive PLC system was installed in two separate rooms as shown in Fig. 3. Experimental setup allows us to check whether an inductive PLC is available on the ship area network (SAN).

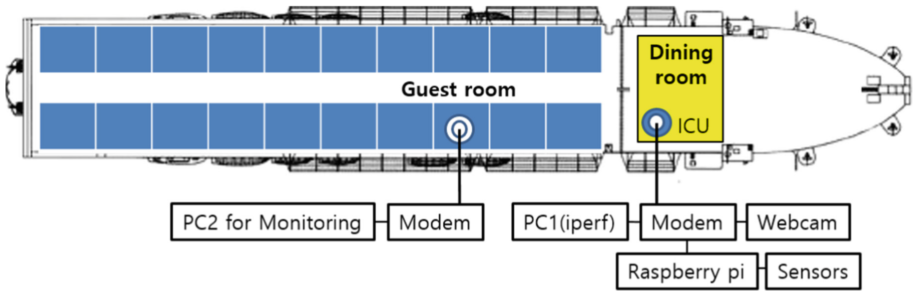

Fig. 3. Experimental configuration on the training ship.

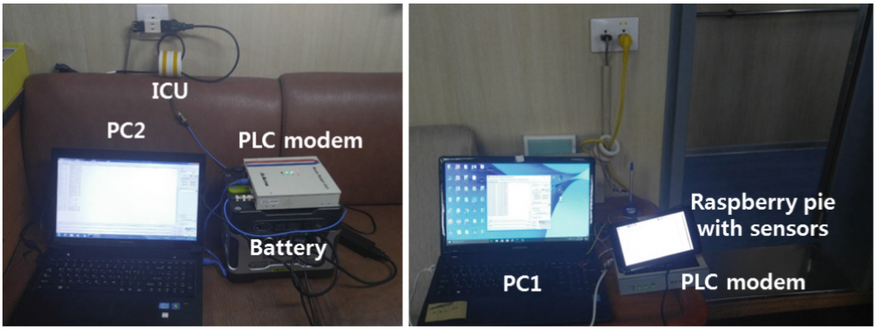

Fig. 4. Photograph of experimental setup. Guest room (left) and dining room (right).

We set the PLC modem installed in the guest room as the master and the other one installed in the dining room as the slave. Devices for data acquisition and transmission, such as a computer (PC1), webcam and raspberry pie, is connected to the slave modem as shown in Fig. 4.

The channel bandwidth can be monitored in the slaver iperf program as shown in Fig. 5. The average data rate measured 10 times in 30 s was more than 12.6 Mbps.

We also implemented a Raspberry pie sensor system that can transmit sensing data such as temperature and humidity by using a nano-crystalline PLC system and confirmed that the sensor data collected at the dining room can be transmitted to the guest room without errors. Real-time images captured with a webcam have also been successfully transferred to PC2. In the same experimental conditions, no communication was made in a PLC system using a ferrite inductive coupler. It can be seen that the magnetic flux density stored in the toroidal core affects the performance of an inductive PLC.

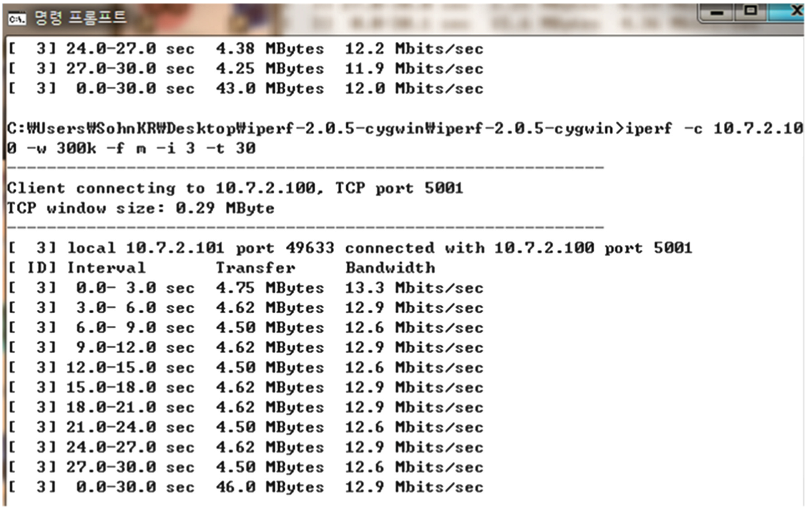

Fig. 5. Data transmission rate using a nano-crystalline inductive coupler

3 Conclusion

We demonstrated an inductive PLC using a nano-crystalline coupling unit that can be applied to the ship. Using a nano-crystalline inductive PLC, we achieved data rates of more than 12 Mbps between two separate rooms in the training ship and succeeded in transmitting images on the same embedded distribution. Because nano-crystalline cores have higher magnetic energies than ferrite cores, nano-crystalline inductive couplers are more suitable for inductive PLC applications in SANs.

Acknowledgement. This research was supported by Mid-career Researcher Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (Grant No: NRF2017R1A2B4010993).

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