CAN OVER POWER SUPPLY LINES ON MODERN AUTOMOBILES

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Communication over power lines has been a debated subject in the past decade. This type of communication was initially intended to be used in broadband internet due to wide reach to domestic and business locations. Building a new network infrastructure involves high cost and takes time, so expanding the functionality of an already expanded network like the power grid raised interest due to its reach and maturity. It also can scale up with little modification. Being a progressive industry, the automotive industry picked up the idea, and a couple of automotive chip manufacturer made CAN over power line available. This is not used in practice yet due to its novelty. This paper will explore and disseminate the usage of CAN over power line in comparison to traditional CAN networks and will give an objective overview of the performance and risks involved.

Keywords: CAN over powerline, diagnostic, automotive, ECU, production.

1. Introduction

Modern vehicles use electronic control units knows as ECUs to fulfill various functionality. ECUs are organized in networks, the most commonly used in today's vehicles being the controller area network (CAN). Each automobile manufacturer can decide on grouping the units in clusters, decide on manufacturer defined diagnostics and find various ways to fulfill functionality as long as the final product is compliant to the regulation of the destination market.

Due to the high volumes of vehicles sold on the last decades, an automobile tends to be a quite cheap product, keeping in account the amount of development, engineering, production and post-sales involved in producing and maintaining it. Because of this this, industry leaves little room for profit as time passes, therefore cost reduction is welcomed in all the involved areas. Electrical and electronics are one of the main targeted areas for cost savings due to its versatility and ease of adaptation. Each ECU component usually has a minimum of four wire connected to it given by the power lines (ground and battery positive terminal) and CAN communication (CAN low and CAN high) as detailed in [4]. Making use of the internet broadband over power grid idea it can be easily observed that this can transfer to our given CAN network. A modern vehicle

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usually contains more than five electronics control units that are connected to at least one CAN network for both intercommunication and diagnostic purposes. This means that if we were to use only the power supply lines for both supply and communication and delete the CAN wiring harness, we would get a significant cost reduction. The only modification needed from an ECU point of view would be the use of a special CAN transceiver which can handle both CAN communication and power supply instead of the traditional one.

There are a few more aspects that need to be covered before proceeding to the actual experiment. One of the aspects is the network architecture. On newly developed CAN architectures, the ECUs are grouped on separated CAN networks based on their functionality and only exchange messages with other networks through gateways. Gateways filter only the mandatory data to make sure the traffic load stays at its lower limit. With CAN over power line the possibility of separating the networks will no longer be an option without adding extra equipment as all the vehicle nodes have a common power supply but re-thinking the architecture to a simpler one and using a minimized message set would help to implement such a solution. One of the other aspects of CAN over power lines is security. Modern vehicles produced after 2018 use a diagnostic gateway, which has the role of filtering intersystem communication from the diagnostics communication, so the intersystem communication will not be visible at the OBD port. Using the CAN over power line will basically offer access to all communication on any power supply termination. There is a more recent asset that can be used to have secure diagnostics given by the security access defined in the ISO 15765 UDS. In this way, the automaker decides which secure key and algorithm are to be used and which units will have defined security access, so the diagnostics security aspect is covered.

There are advantages and disadvantages of using this type of communication, but we must be objective in exploring and analyzing the reliability and performance. For the experimental data trial versions of specialized software were used to generate, collect and visualize data in a more accurate way.

2. Objective and method of research

The objective is to analyze and compare the traditional CAN communication to the CAN over power lines communication. Aspects of reliability, performance, cost, and design will be taken into consideration. A modern vehicle can contain more than 10km of wires. Given the fact that modern vehicles electrical system architectures consist in higher number or ECUs and all of these units need access to at least a network, a significant bit of the 10km wiring harness is allocated as CAN data lines. Along wiring cost saving, an additional cost saving can be also achieved from reducing the respective connector pins, downsizing the connectors. The high number of electronic control units and their distribution demands not only extra wiring to connect to CAN or FlexRay networks, but also bigger connectors and pins, thus removing the communication wiring harness and moving it on the power lines would be a great cost saving. An associated cost regarding the fitting the ECUs with special CAN over power lines transceivers rather than usual CAN transceivers, but still as integrated circuits of this type are extremely cheap, adopting this concept would save manufacturers financial resources from the bill of material and time by easing up the production process. In modern automotive cost planning even the slightest cost saving is considered. For the ASK experiment, a theoretical hypothesis was taken into consideration with results which quickly led to conclusions. For the PSK experiment, a circuit board was built in order to inject random noise to the system. The present research has been approached with regards to generating a new simple architecture that can easily use the CAN over power line communication method. Contingent aspects as modifications that need to happen for creating this type of architecture and production line equipment adaptation have been taken into consideration and mentioned by case.

3. Hypothesis and signal simulation.

The CAN over powerlines system has a lower noise and interference immunity than the standard CAN bus where a twisted pair is used. The performance would be severely decreased if used on an on/off switching inductive load circuit branch, so this concept is only recommended to be used for non-safety related vehicle features due to possible loss of telegrams under high load conditions. A real-world example would consist of using the CAN over powerlines on distributed systems used for comfort features where messages are simple, can be send multiple times for error correction purposes and do not imply safety. The overall slower performance would not be noticed by the end user so the manufacturer would benefit of the same features at a lower cost.

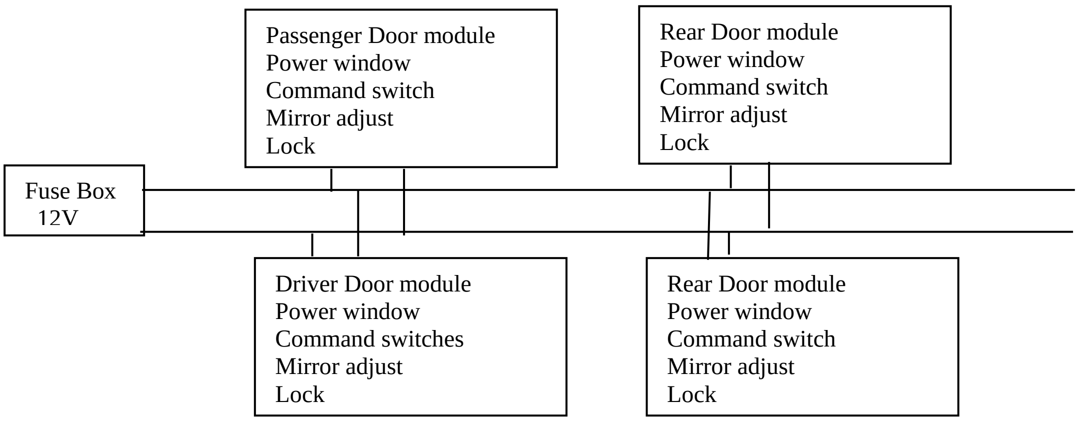

Fig. 1. Vehicle door control system

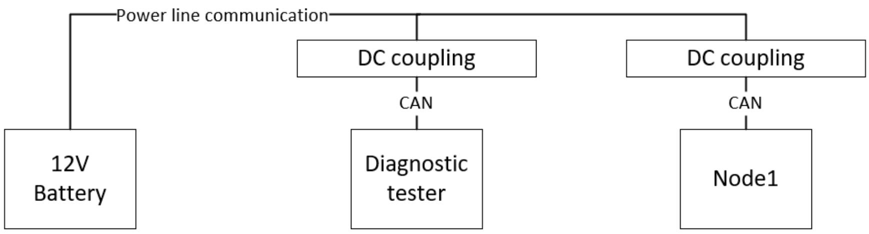

Fig. 2. Nodes DC coupling

As the sending and the receiving paths are similar for the purpose of this research article the receiving path of the DC coupling shown in Fig. 2 will be discussed with a similar approach as in [5]. In order to use power line communication, the usable frequency defined in the CENELEC is up to 148.5 kHz. The circuit built for the experiment used a single carrier frequency of f=113.9 kHz so this fall within the CENELEC limits. There are a couple of solutions in which the DC coupling can modulate and demodulate. The first solution would be to transmit only the dominant bits as in Fig. 3 which will offer a result similar to ASK modulation.

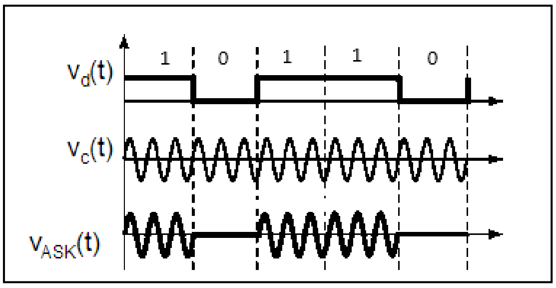

Fig. 3. CAN ASK modulation

As seen in Fig. 7 and detailed in [6], there will be two values for our ASK modulated signal as it follows in (1) and (2).

$$S(t) = A_0 \cos(2\pi f_c t)\,, for\ 0\ logic \quad (1)$$

$$S(t) = A_1 \cos(2\pi f_c t)\,, for\ 1\ logic \quad (2)$$

A reliability issue would obviously occur if the CAN transceiver would fail into an open circuit scenario. Then it would create confusion between a recessive bit and the carrier itself.

To improve this method a second phase can be introduced for the recessive bits. In this way, the CAN messages would be transmitted using PSK. By using two different phases for recessive and dominant bits, now the system is protected against false recessive bits.

$$S(t) = A\cos(2\pi f_c t)\,, for\ 0\ logic \quad (3)$$

$$S(t) = A\cos(2\pi f_c t + \pi)\,, for\ 1\ logic \quad (4)$$

The result of the simulation can be seen in Fig.7.

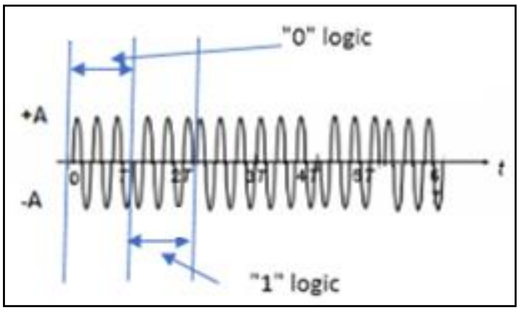

Fig. 4. CAN PSK Modulation

Detection of the PSK carrier is covered in [2]. Given the following propriety:

$$cos^2 A = \frac{1}{2}(1 + \cos 2A) \quad (5),$$

and the signal: S(t) = ± $A\cos(2\pi f_c t)$ (6),
The resulting signal will be: R(t) = ± $A\cos(2\pi f_c t)$ x 2 $\cos(2\pi f_c t)$ (7),

with the following two cases:

R(t)=2$A\ cos^2(2\pi f_c t)$ = A [1+ $\cos(4\pi f_c t)$], for„0” logic (8)

and

$R(t) = -2A\ cos^2(2\pi f_c t)$ = -A [1+ $\cos(4\pi f_c t)$], for „1” logic (9)

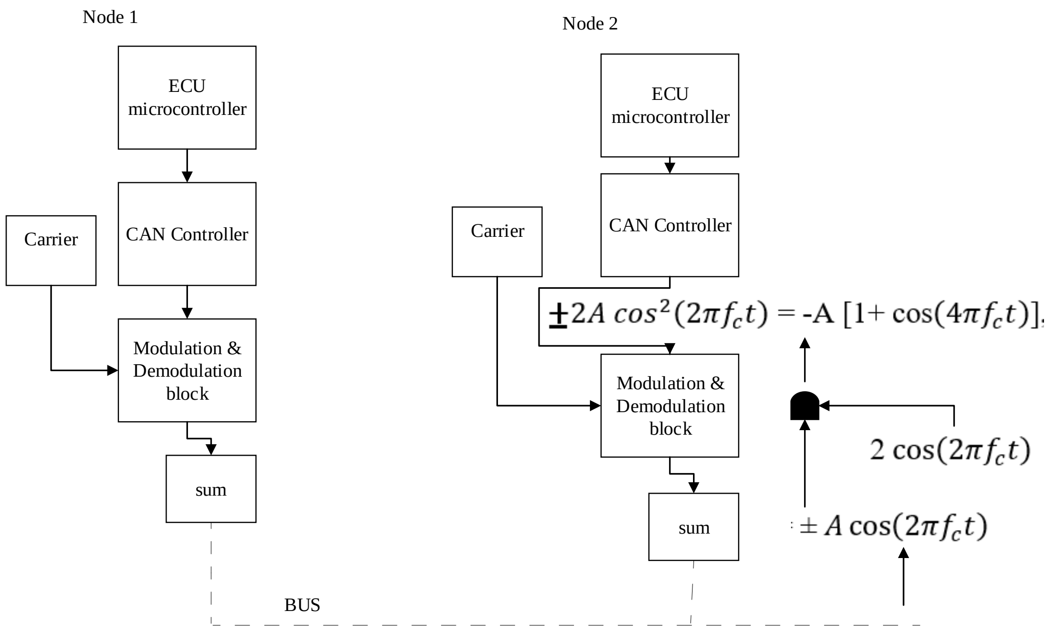

Fig. 5. Demodulation block diagram

A demodulation example is displayed above in Fig. 5. The steps for preparing the signal to be processed by the CAN controller (6), (7), (8) and (9) were included in the diagram. Following the demodulation block diagram, the paper will approach an example circuit design in Fig. 6. The experimental values have been used to build a circuit board and measure the filtered, demodulated CAN signal. The signal could be successfully decoded using a simple oscilloscope (Fig. 7).

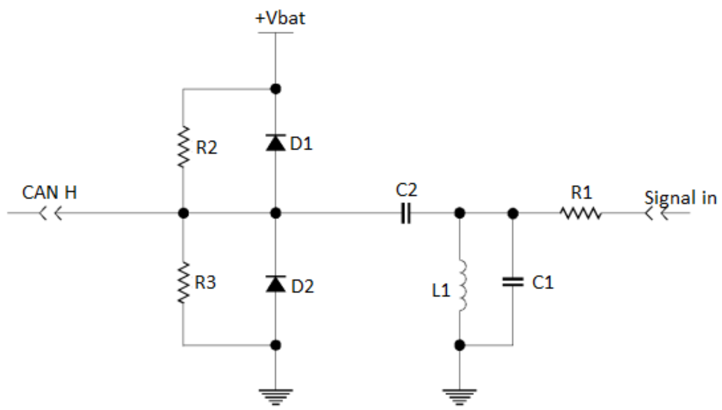

Fig. 6 Demodulation principial schematic

R1 is used as input impedance for the receiver. The L1 C1 resonant bandpass filter is calculated in (10) for our 113.9 kHz signaling frequency using (1) and a common capacitor C1= 1.5µC. Using the formula, we get L1= 1.3mH. For isolating the DC component C2 is used.

$$f_r = \frac{1}{2\pi\sqrt{L1\,C1}} \qquad (10)$$

The D1 and D2 diodes will limit signal of high amplitude to protect the CAN transceiver of the ECU. Finally, resistor R2 and R3 are going to be used as a voltage divider to make sure the CAN H will have the correct voltage for CAN high.

With a frequency of 113.9 kHz, the bitrate would be very low around 10kbps which works for diagnostic purposes but can have a relatively high error rate in the case of simultaneous intersystem communication and diagnostics. Higher frequencies of MHz order can be successfully used to achieve higher speeds but are out of CENELEC. Currently, CENELEC does not impact the automotive domain so special regulation can be created in order to use this novelty. A third solution is to use baseband modulation which can achieve greater baud rates. For this type, a single-chip PLC CAN transceiver can be used.

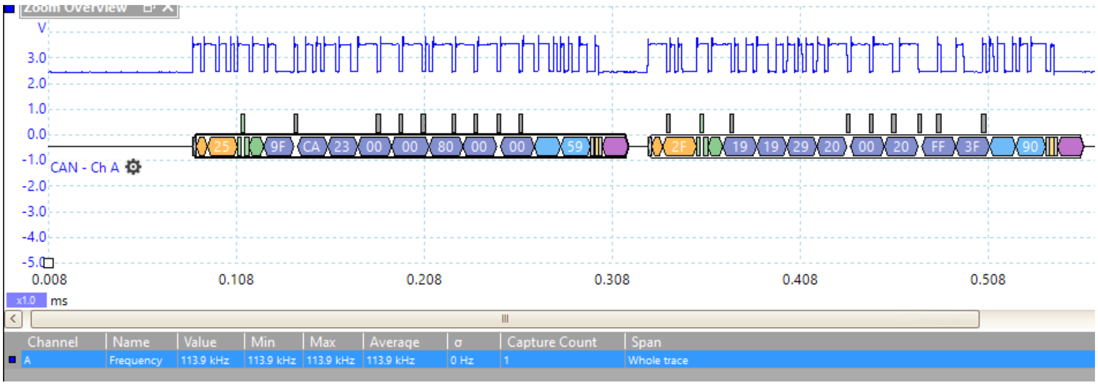

Fig. 7 Demodulated signal DC filtered (Demonstration PicoScope software was used)

Due to using a 12V DC battery and the original CAN network twisted pair for the bus, the noise was reduced. Using the baseband modulation, the circuit has lower noise immunity. On a vehicle, there are many inductive loads that can disturb the power lines such as HVAC blowers, power window motors, Engine cooling fans, door lock actuators. As a solution, the PLC CAN transceivers use differential circuits which take the power line voltage as reference. In this way, there should be little to no impact on the CAN transceiver performance level. As it can be seen from the oscilloscope measurement the serial decoder was able to read the CAN message without any problems. The Base-band modulation spectrum was kept to near ideal due to using twisted wire technology for the power lines and termination resistors, same as traditional CAN networks. In the figures below, it can be noticed that the spectrum of the measured signal is close to the ideal, theoretical figure.

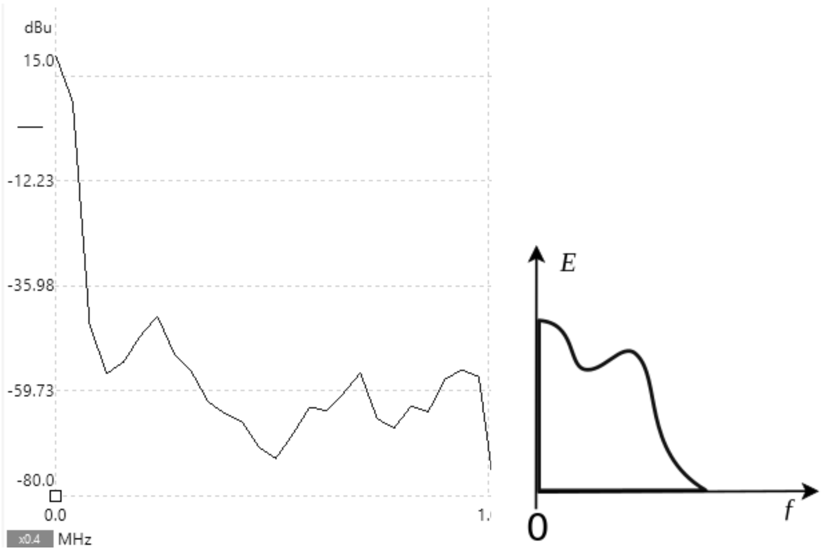

Fig. 8 Experiment result (left side) compared to the ideal case (right side) (Demonstration PicoScope Software was used for measurements)

4. Electromagnetic immunity considerations

We should set the correct expectations from the start for the presented CAN over power lines system. The aim is to use the solution for non-safety related systems. Main expected use should be simple systems like the door control system Fig. 1 or rapid service diagnostics operations (service interval reset, read trouble codes, etc.). Using the system over parallel wiring configuration would be prone to high susceptibility, but in the automotive world all ECUs power supply lines come in low section wiring grouped in branches, so it is easy and cheap to get the powerlines in twisted pairs. To add electromagnetic immunity capabilities to the system so it can integrate future, more data demanding applications we added decoupling inductors and coupling capacitors (as in Fig. 2) which also come as cheap passive components that can easily be integrated on load's or ECU's circuit boards. Therefore, we consider the following setup in Fig.9 below for comparison with the common case automotive CAN bus.

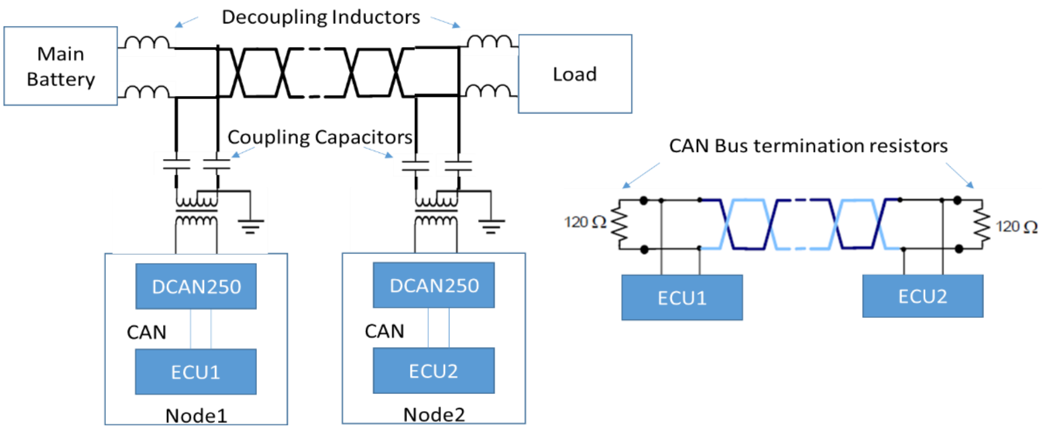

Fig. 9 a) CAN over power lines (left) b) normal automotive CAN Bus (right)

With such a design as the one in Fig.9 a) the solution should have similar conducted and radiated immunity to the commonly used CAN Bus solution in Fig. 9 b). Practically we would look at the 10 kHz to 500 kHz frequency domain but, for the experiment we can extend to up to 2.5 MHz (DCAN integrated circuit carrier) and the maximum forward power was set to 15W to follow the RE 310 and CE420 standards. Also, to comply with the CE420 the bulk current injection method was used in the simulation.

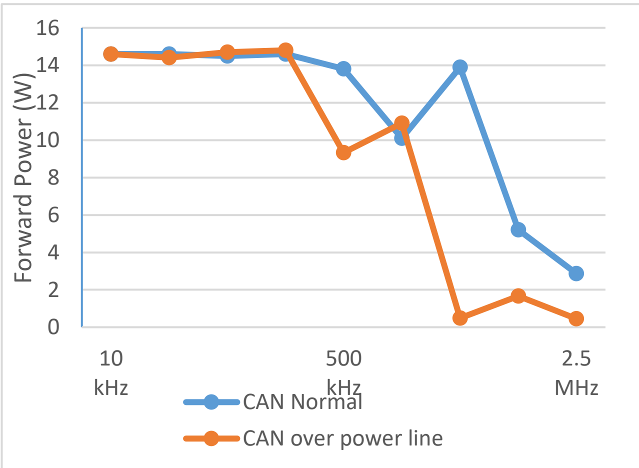

Fig. 10

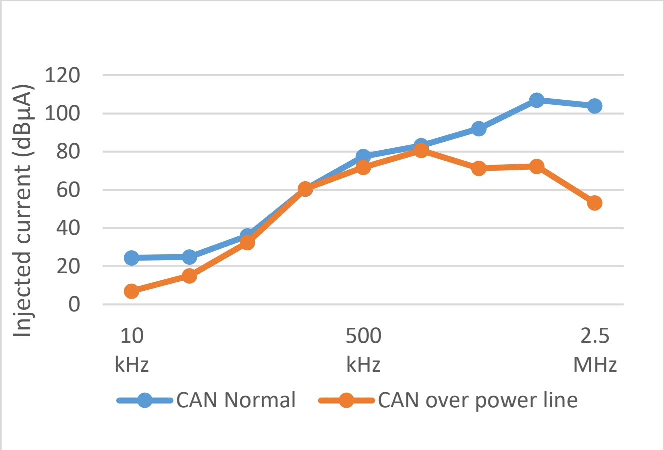

Fig. 11

From the results displayed in the above Fig. 10 and Fig. 11 it is noticeable that in the area of interest to an extent up to 500 kHz the conducted susceptibility of the CAN over power line is quite similar to the usual CAN bus. The performance is prone to degradation near the 2.5 MHz limit as this is the carries frequency of the DCAN integrated circuit, but it is not very far from the normal CAN bus. With regards to radiated immunity the test would require special environment and use of the transverse electromagnetic cell (TEM cell) method. In comparison to the conducted immunity, the radiated susceptibility simulation would leave room for too much error making it obsolete, hence the mention of the principal drawing of the TEM cell in Fig. 12 and mention of the mitigation available for radiated disturbances. The most efficient method commonly used in the automotive industry is the ferrite, which will would efficient and cost effective.

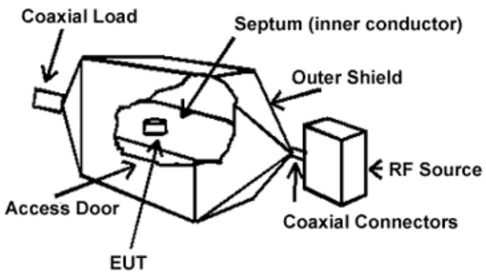

Fig. 12 TEM cell (source: https://www.eetimes.com/)

EUT - Equipment under test

5. Conclusions

Ease of implementation and the massive cost reduction initially inclined the balance strongly on using the CAN over power lines method. Performance is similar to a traditional CAN network given the frequency domain of 10 kHz to 490 kHz. This frequency domain can cover baud rates of 250Kbps and handle collisions using the CSMA/CA +AMP protocol. With collisions are experimented in [2] and the proof that the serial decoding works perfect in Fig.6 we can conclude that the DC coupling of node does not impact the number of collisions. The microcontrollers are also equipped with a noise protection mechanism. Also, high voltage and low voltage present similar risks on both traditional and CAN over power line systems. There are two things where a traditional CAN network is better the newer CAN over power line and those two domains are given by the freedom of designing a distributed architecture and security specific. Both items are dictated by the possibility of separating sub-networks with CAN gateways. For the purpose of cost on simple architecture design, a CAN over power line network will always win. Production equipment will also bring cost reduction, being cheaper to install both diagnostic tester and power supplies as an “all-in-one” system that only connects to the car battery. For battery electric vehicles (EV) or hybrid plug-in vehicles (P-HEV) this could also be an advantage on data exchange between the vehicle and the charger power station and further on to a dealer maintenance server or the user’s mobile phone or laptop. Depending on the automakers will trade security and complex architecture for cost the traditional solution could be changed over to the CAN over power line newer network type or use a combination of the both with the obvious advantage of EV / P-HEV vehicle to charge communication.

The results presented in the current paper open the path for future research with regards to improve the use of communication over powerlines and developing a method for simulation radiated immunity. Currently the presented solution is not recommended to be used in safety related systems or powerlines with inductive loads. New methods can be developed to make the solution more reliable surpass the limitations especially the use in inductive loads networks.

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