International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-7, Issue-6, March 2019

Locating Wire Fault using Time Domain Reflectometry in Controller Area Network based on Kelvin Resistance (4-Wire) Method

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Abstract: ***CAN is a multi-master bus standard used to transfer the information between electronic control units (ECU's) without a host computer. CAN network is used in the branch of technology as well as in industry. Fault occurrence in CAN system makes complicity in the data transmission between devices (ECU's) and affects the efficiency of vehicle. Wire faults occur at irregular intervals are not easy to detect and locate in the CAN bus. The resistance of the wire can be measured by using four wire kelvin resistance measurements. So, this paper proposed a new method for detecting the open and wire short fault using Kelvin 4-wire resistance method in order to reduce the approximately 20% measurement error compared to the existing two wire resistance measurement and the TDR approach is used for locating it. This proposed approach is implemented using Arduino based CAN controller. The overall performance analysis of the proposed system is shown using ECU's as a sender as well as receiver, it able to communicate with the CAN transceiver. The predetermined threshold resistance values are utilized in detection of open and short wire faults (Kelvin-wire resistance method).Whereas the amplitude and time interval of the reflected signals are used in locating the faults (simple TDR approach).The experimental result of the proposed system has been discussed to show the better performance by measuring and analyzing the reflected signal, we can identify the exact size and location of the fault in CAN bus.This proposal is inexpensive for CAN system trouble shooting and effective in identify wire faults prior to the user`s disruption.***

Keywords: Can Bus, Tdr, Ecu,Rta, Jtag.

I. INTRODUCTION

In the era of In-Vehicle network, the electronic devices were connected by using wiring system from one device to another. In the demand of users, many more electronic devices needed to build in vehicles. So, it made the system as heavy and expensive.

Revised Manuscript Received on 30 March 2019.
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To reduce the cost, complexity and heaviness there is a need of replacement of wiring system in vehicle networks [1, 2].In 1985, CAN was developed by BOSCH for In-Vehicle network. It is low in cost and prioritized error resistant network. CAN is a multi-master serial bus used for connecting ECU's. ECU's is a gateway for communication between devices over a 2-wire bus. These wires are 120 Ohm twisted pair [3]. In modern automobile, we are using more than 70 ECU's and used for transmission in ABS, Power Steering, power windows, doors mirror adjustment, battery recharging etc., It gets message from actuators and sends it to ECU's via sensors [4]. CAN network uses in the branch of technology and industry concerned with both aviation and space flight for the data analysis and control systems i.e. (fuel level, Pumps and linear actuators). Sterile supply technician's use CAN network in Medical equipment. In fact, many hospitals started to use CAN network to operate lights, CCTV cameras, X-ray machines, tables and Patient details with CAN systems.CAN bus also used in embedded applications such as lifts and escalators.In Non-Industrial applications, CAN based systems are used in telescope, Coffee machines, sports cameras, telescopes, automatic doors and lights. There is a chance of faults occur at irregular intervals causes accidents and increases the cost and reduces user's satisfaction and affects the quality of system [5, 6].To increase the quality, there are more researches on diagnostics of CAN faults has been conducted in recent years. In the need of more security, USA announced that OBD II CAN standards have been mandatory for all cars and light trucks since 1996. CAN bus use one of five protocols of on board diagnostics standard [7]. Open wire fault in CAN interrupts the message communication between the ECU's and causes the corruption in transmission of data at irregular interval, these kinds of faults are not easy to find and locate. SO, identification and fixing these faults are time consuming process and complicated for technicians hence it is more challenging to locate and detect intermittent faults. In SA, MVA and RTA in Europe analysed to find the reason for road accidents and they concluded that the accidents are occurring due to three factors such as road conditions, device failure (brake failure, tire failure and steering & suspension) and abnormal driving speed. So, they have introduced safety devices such as ABS, radial tires and power steering, etc. are communicated via CAN bus. ABS CAN system prevents the wheels from locking up during emergency braking to avoid accidents. Un-even or worn-out tires are the most serious problem leads to catastrophic accidents.

So, we have introduced CAN system for auto checking of tire pressure at regular intervals (1000 miles). Power steering CAN system enables to go around road obstacles to avoid accidents [8, 9]. According to the survey of Georgia uniform vehicle accident report 2010, says that 6674 roads dead are happening due to vehicle failure, in that certain accidents are happenings due to failure of Inter CAN system. To increase the safety in vehicle network, CAN plays an important role for maintenance and regular efficiency check for the CAN system. Hence there were various approaches to check the healthiness of CAN bus such as physical signal approach and message based approach [10, 16]. Huetal [11] proposed an error frame counter as an online fault diagnosis; each ECU sends message to other ECU's if any error occurs the error frame counter gets incremented when it reaches the threshold value it sends the message as CAN busfailure. Another robust method if faulty nodes are detected it sends the information about the faulty node to all the healthy nodes to declare CAN bus is failure. But, these kinds of messages oriented approaches were failed to detect open and wire short faults in CAN bus. Physical signal approach consists of inductance, capacitance and resistance measurement to locate open and short faults [12]. Existing method to measure bus resistance via two wire resistance approaches introduces the 20% of measurement error i.e. (it adds the device under test resistance plus the lead resistances). So, we propose a four-wire kelvin resistance method to measure the device under test resistance directly [13, 14]. It measures the bus resistance accurately compared to the two-wire method. Many proposed TDR approach to detect the dis continuity in CAN bus. If we use TDR approach for detecting the faults at regular intervals in each node is expensive and time consuming process [15]. Our objective is to develop low cost, feasible, and accurate and safety approach to detect the fault by measuring the bus resistance and locate it using simple TDR approach.

II. WIRE FAULT SCENARIO IN CAN BUS COMMUNICATION

In this section, the behaviour of the CAN Bus in the case of wire faults are examined and the CAN Apparatus model is designed based on the CAN Bus standard.

The OSI layer characteristics of the CAN bus are explained in ISO-11898-2 [16]. The Physical layer of the CAN play an important role in CAN communication. It consists of bit encoding and decoding, re synchronization and bit timing.

The sub layer of the physical layer is realized by TxD and RxD and also supports 5 volts and 3.3 volts CAN version. Architecture of the CAN consists of ECU's which transmit and receive messages using transceiver and communicates via twisted pair cable with the terminal resistor 120 ohm at each end. Can cable have a maximum length of 40 meters at the data rate of 1 mbps.CAN consist of CAN-H and CAN-L wires. Both the wires transmit equally splitted voltage at the recessive state but in case of dominant state CAN-H carries higher voltage than the CAN-L wire. In case of short wire fault scenarios, If the voltage on the CAN-H wire increases, Resistance on the wire also gets increases. If the wire has Open wire fault, voltage and resistance on the CAN wire gets decreases [17].

According to the CAN Bus Standard ISO 11898-2, the differential resistance of the CAN wires is between 10kOhm to 100kOhm compared to the terminal resistance i.e. 120 Ohm.

III. DETECTION OF WIRE FAULT USING KELVIN MEASUREMENT

When an ECU's transmit no messages on the CAN, There is no voltage drop or resistance on the bus. Based on the CAN specification, The behaviour of CAN bus during wire fault can be examined as follows, Whenever an ECU's send a message on the bus, the transceiver will detect a bit error and goes to the dominant state. So there is a voltage drop or decrease in resistance of the wire happens.

In order to detect the faults in wire, There is a need of examine the resistance or voltage drop of the CAN wire at regular intervals. So the resistance of the wire can be measured by using four wire kelvin resistance measurements. It will decrease the twenty per cent of the measurement error compared to the existing two wire resistance measurement [18].

To estimate the resistance of the wire, the voltage and the current need to be calculated first. Voltage can be measured by sensing it with the different positions but we cannot have current sensor in the ECU's. So low cost shunt resistor is used to measure the current on the CAN Bus. Based on the Kelvin four wire measurement, Unknown resistance can be measured by using Known resistance i.e. 120 Ohm terminal resistor.

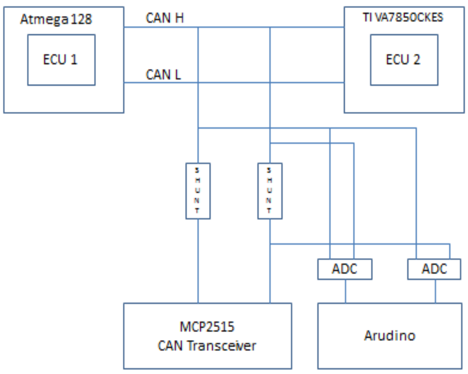

Fig. 1 Wire Short Fault detection Circuit

Apparatus required to measure the bus resistance of the CAN wire using Four Wire Kelvin measurement in Fig.1. Resistance can be measured at regular intervals on the CAN bus. If the measured resistance is within the threshold resistance, there is no faults detected on the CAN Bus but if it is not within the threshold, Wire fault has been detected.

Threshold resistance of the CAN Bus is defined as the differential resistance between the terminal resistance and CAN bus resistance [19].

IV. LOCATION OF WIRE FAULT USING TDR APPROACH

In order to locate the fault in CAN Cable, we are using Time Domain Reflectometry method in Fig. 2 (i.e.) We are transmitting the known signal to the cable under test, In order to analyse the reflections, It will send out the incident signal to the CAN Cable (Twisted pair cable) and listening to the reflected signal, Based on the reflections, if the cable hasnormal impedance and is correctly constructed, then there will be no reflections and the remaining transmitted signal is absorbed at the one end. Instead if it is found any variable impedance, then some of the transmitted signal is reflected back to the source.

If the incident signal has step increase in the impedance, the same will be reflected in reflected signal. If the step decreases in the incident signal, the reflected signal will have the decrease impedance [20]. The amplitude of the reflection not only depends on the resistance change and also loss on the cable.

The reflections are marked out as a function of time and the time difference can be taken as the length of the cable. So Amplitude change in signal can be considered as the size of the fault and the reflected signal time difference is calculated as the length of the cable.

TDR approach can be implemented via the T connector, one end of the connector will have the known signal and opposite end will have the cable which you need to be tested and the upper end needs to be connected to the device whereas magnitude and time of the signal is estimated [21].

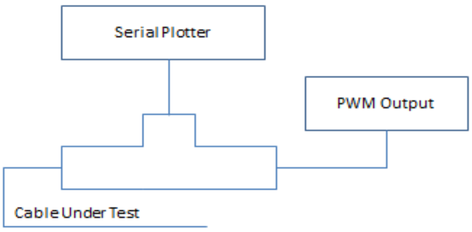

Fig. 2 Time Domain Refelectometry System

V. VALIDATION RESULTS AND APPROACH COMPARISON

We have taken two ECU's for the experiment. One ECU acts as a sender (ATMEGA 128 Microcontroller) include 8 channels PWM signals, Advanced RISC Architecture and 10 bit ADC and the other ECU acts as a Receiver Texas instruments (TMS320F28335) includes turbo can, RS-232, JTAG connector, and on board USB JTAG emulation. Both ECU's can be communicated by the use of CAN Transceiver (MCP2515 CAN Transceiver). Room Temperature is measured by temperature sensor which is inbuilt in transmitter is successfully transmitted to the receiver in Fig 3.

Fig. 3 Sending Data (Room Temperature) from ATMEGA 128 Microcontroller

Fig. 4 CAN Transceiver (Sender – At mega 128 Microcontroller, Receiver – Texas Instrument, CAN Module – MCP2515)

CAN communication can be analyzed by using Code Composer Studio. In Fig 5, Data 1 and Data 2 can be successfully send and receive between the ECU's.

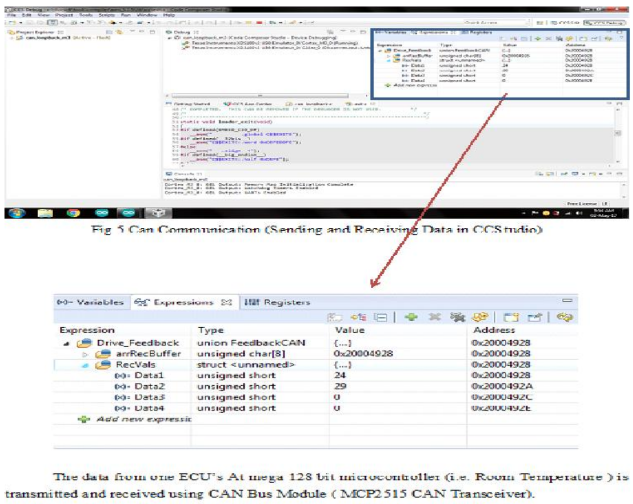

Fig. 5 CAN Communication (Sending and Receiving Data in CCStudio)

In order to check the health of the CAN Bus, we are using physical signal based approach to identify the open and short wire fault in CAN Bus. In our proposed approach, we are measuring the bus resistance by using four wire resistance kelvin methods. If the measured resistance is within the threshold resistance, there is no faults in CAN Bus in Fig.6.

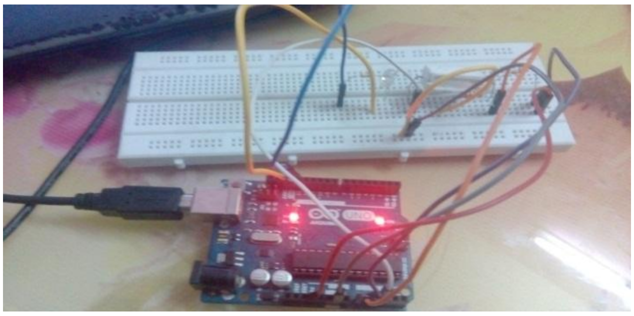

Fig. 6 Four Wire resistance Measurement Kelvin Method Circuit with Arduino

Two wire Measurements introduces nearly 20 % error compared to the four wire kelvin method in Fig. 7. If the measured resistance is not within the threshold resistance, the fault has been detected and then we are giving alert signal by using blinking LED in Fig. 8.

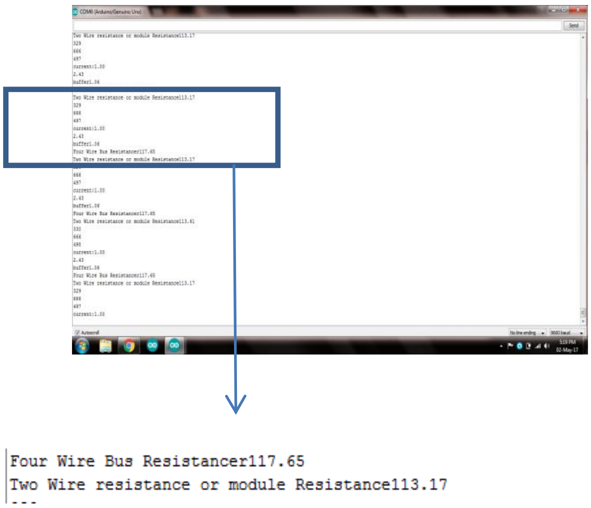

Fig. 7 Comparison between four wire versus two wire measurement Values

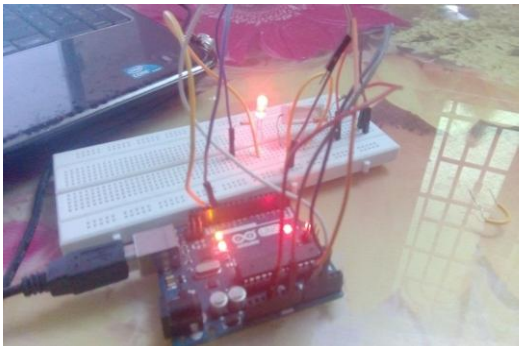

Fig. 8 Wire Fault detection (indicated by LED in blinking mode)

In order to locate the fault in CAN Cable, we are using Time Domain Reflectometry method (i.e.) we are transmitting the known signal to the cable under test. PWM signal can be generated from Arduino 9th Pin on Fig.9.

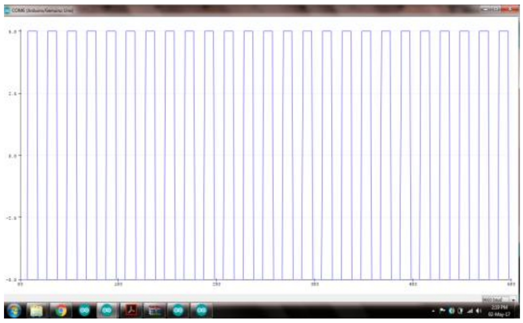

Fig. 9 PWM Signal from Serial plotter port in Arduino

We are transmitting the known signal to the cable under test, in order to analyze the reflections, It will send out the incident signal to the CAN Cable (Twisted pair cable) and listening to the reflected signal, Based on the reflections, if the cable has normal impedance and is correctly constructed, then there will be no reflections and the remaining transmitted signal is absorbed at the one end. Instead if it is found any variable impedance, then some of the transmitted signal is reflected back to the source. The short circuit fault can be detected as shown in fig.10, and its distorted reflected signal is shown in fig.11

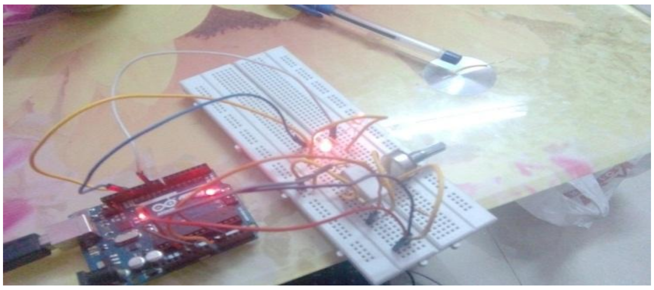

Fig. 10 Detecting and Locating Wire short fault circuit with Arduino

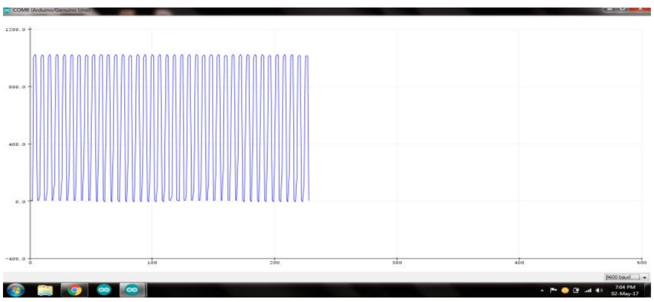

Fig. 11 Distorted reflected signal from CAN Bus Wire

Note that the short wire fault can be detected and measured in Fig.12. Parameters can be calculated and compared between two wire and four wire resistance measurement as shown in Table 1.

Let assume Vo is Output Voltage of the PWM signal, td denotes as the Duration of the pulse, tr, denotes as the Repeat ion time of the pulses, Vin as the Input Voltage, Is as the Current from Shunt Resistor, R1 as the Known Resistance (120 Ohm), and the Vavg denotes average of the Module resistors.

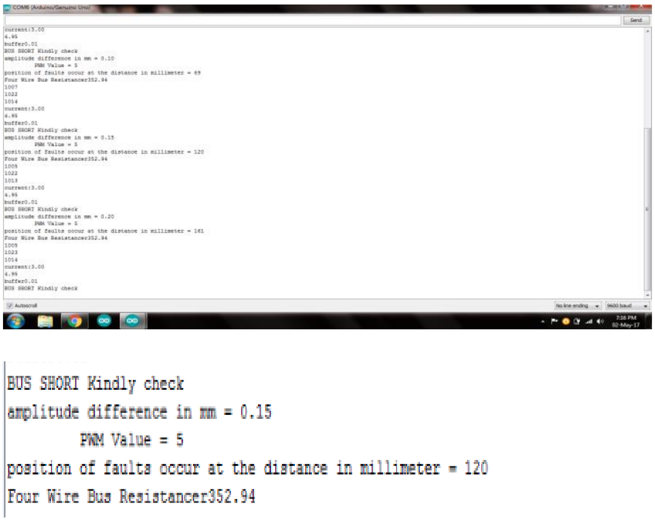

Fig. 12 Overall Outputs in Serial Monitor

PARAMETERS	ACTUAL VALUE	MEASURED VALUE IN TWO WIRE METHOD	MEASURED VALUE IN FOUR WIRE METHOD	DIFFERENCES	MEASUREMENT ERROR WITH RESPECT TO ACTUAL VALUE	ERROR %
VOLTAGE (Vin) (volts)	3.3 V	3	3.2	0.2	0.096	20%
CURRENT (Is) (Amps)	5	4.66	4.96	0.36	0.992	36%
BUS RESISTANCE (R1 * Vin/ Is shunt current) (ohms)	120	113.17	117.65	4.48	0.98	44%
MODULE RESITANCE (R1 /Vin * Vavg) (ohms)	0.85	0.78	0.82	0.04	0.96	4%
SIZE OF THE FAULT (vo* td/tr)	0.2	0.16	0.18	0.02	1	2%
LOCATION OF FAULT (td/2) in mm	9.4	6.89	8.46	1.57	1.06	15%

Table 1: Comparison of parameter between two wire and four wire method

VI. CONCLUSION AND FUTURE WORK

In this work, we primarily focus on detecting and locating the open and short wire faults in CAN bus wire. It can be detected by measuring the resistance or voltage drop across the CAN bus wire with the help of four wire kelvin measurement. Four wire measurements reduce the lead resistance value by measuring the voltage directly under test in order to eliminate the lead resistance. So we can reduce nearly 20% measurement Error compared to the existing two wire systems. When the measuring resistance is not within the threshold resistance it can be marked as the fault occurrence. In order to locate the fault in CAN bus, we have generated PWM signal from Arduino and given as the incident signal to the CAN bus. By measuring and analyzing the reflected signal, we can identify the exact size and location of the fault in CAN bus. The experiments have been implemented on an Arduino UNO for both detection and location of faults. So, the results show the new approach, compared to other existing approaches, is robust, accurate and low cost. The Future work of the CAN communication can be extended by implementing the light weight Authentication method based on chained hash algorithm. It will be useful for user could authenticate N times before the hash chain is exhausted [22, 23].

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