CHANNEL CHARACTERIZATION FOR ULTRA-WIDEBAND INTRA-VEHICLE SENSOR NETWORKS

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ABSTRACT

This paper presents an ultra-wideband (UWB) testbed and its application to characterize channels for intra-vehicle automotive sensor networks. A received pulse width of 300 ps is achieved both in laboratory environment and outdoor over 60 m. Channel characteristics are thoroughly measured for a car. Different settings are investigated, including UWB signal propagation from rear wheels to the engine compartment area, within the engine compartment, and from within the engine compartment to the passenger compartment. The study found: (a) communications between a transceiver at the bottom of the engine compartment and rear wheel speed sensors can be achieved at 330 mega-pulses per second using UWB technology without inter-symbol interference; (b) When the hood is shut, UWB communications within the engine compartment can achieve 476 mega-pulses per second when there is a line-of-sight, or 50 mega pulses per second when there is no line-of-sight; (c) The received signals for UWB communications within the vehicle are very stable, and have negligible fading. Pulses traveled through different paths are distinct in the received signals. This means that the UWB technology has resolved mutipath. Therefore, UWB can provide sufficiently high data rate for hundreds of wireless sensors in future automotive vehicles. The negligible fading in the received signals makes it much easier to design transceivers with low cost and low complexity.

I. INTRODUCTION

The automotive industry has been limited by the available sensor technology. Sensors are now the weakest electronic links in vehicles [1]. Revolutionary changes from the conventional wired sensors are required to reduce cost and enable new improvements to vehicle performance.

Cost reduction is always critical in automotive industry. Our research has shown that it is feasible to achieve significant cost reduction through employing ultra-wideband (UWB) wireless sensors instead of existing wired sensors. Improving vehicle safety, increasing fuel economy, reducing emissions, and improving reliability are all extremely important to the automotive industry. This has resulted in the proliferation of powerful electronic control units (ECU) and their associated distributed sensing and actuators. In 2002 the average number of sensors on an automotive vehicle was 27.1, which translates to a total of 447 million sensors for the industry [1]. By 2009, the total sensor volume for the automotive industry will grow to 659 million valued at $4.15 billion dollars [1]. The development and deployment of these electronic control systems have resulted in enhanced automotive performance. However, these systems are limited by the available sensing technology.

Tremendous possibilities exist to significantly reduce the cost of sensor networks in automotive vehicles and improve the automotive performance through new sensing architectures and capabilities [2]. Many applications could be greatly improved if there were available techniques to measure critical parameters that can not be easily measured.

If the limitation of having a physical connection and wires could be removed, vehicle systems would undergo tremendous changes and enable efficiencies in other areas such as manufacturing and design. Providing an on-board UWB sensor network for vehicles will enable the development and implementation of the sensor systems in automotive vehicles.

It is evident that there is tremendous benefit in developing and deploying vehicular wireless sensor networks. Such networks must be able to perform in an automotive environment, provide reliable data in a timely manner and maintain communication in hostile conditions. The hostile conditions could include extreme temperatures, multi-path, exposure to both impulsive and broad bandwidth electrical noise sources, unintentional and intentional jamming. Further requirements would include security of data, low probability of intercept, and low cost, given the extreme pressures of the worldwide economy.

For wireless sensors in automotive vehicles ultra-wideband (UWB) is the best among all of possible technologies. The FCC Part 15 Section 15.503 definition of a UWB transmitter is "An intentional radiator that, at any point in time, has a fractional bandwidth equal to or greater than 0.2 or has a UWB bandwidth equal to or greater than 500 MHz, regardless of the fractional bandwidth." UWB has moved in the public sector with several vendors offering chipsets. UWB is capable of supporting applications that include high power military applications to low power uses in vehicles, laptops and medical RFID systems [3,7-11].

UWB technology is the best to resolve multipath of a communication signal reflected in the semi-closed metal environment within an automotive vehicle. This super resolution of multipath provides stable signal without fading and high capacity in wireless communications [9]. It simplifies receiver design and implementation and leads to lower receiver cost. The large bandwidth of UWB technology gives the best resistance to intentional and unintentional interference, and makes it a good fit for applications where low power and signal reliability are critical such as in an engine compartment. None of these features is available from any of the existing wireless technologies [4,5].

In summary, the automotive industry needs more sensors for vehicles in locations unreachable by wires. UWB is a leading technology to enable these advanced sensors and replace existing wires in vehicles. Research is needed to understand the UWB channel characteristics in the vehicle environment. Development and testing have to be performed to demonstrate that UWB sensor network can meet the security, reliability and performance requirements of the on-board vehicle environment.

II. UWB TESTBED

We have developed a UWB testbed and successfully applied it to collect data in UWB channel propagation in automotive vehicles. Fig. 1 shows one setup. A function generator triggers the Pulse Generator 3600 by Picosecond Pulse Laboratory. The pulse generator output is fed into a transmitting antenna. A receiving antenna picks up the signal. The antenna output is sampled and recorded by a Tektronix TDS6124C Digital Storage Oscilloscope (DSO) with 12 GHz front analog bandwidth and 40 Gsps per channel for 2 channels. Fig. 2 shows the waveform when the Pulse Generator output is connected to the TDS6124C DSO through a PSPL5510 attenuator and an SAC-18G-3 3m cable. The pulse width is 80 ps.

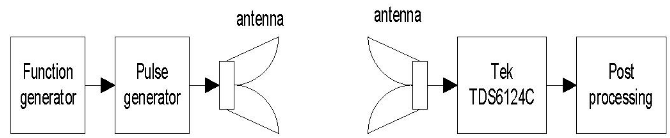


Fig. 1 Block diagram of the UWB channel sounding setup.

Fig. 2 The UWB pulse at the Pulse Generator output.

Fig. 3 shows the received waveform when the transmitting antenna and the receiving antenna were 211 inches away directly facing each other at the height of 44 inches in our lab. Antennas perform differentiation to the signal [Fer]. Fig. 4 shows a sample of the received noise when the transmitter was turned off. Counting the same noise process in Fig. 4 to the received signal in Fig. 3, one can see that the received signal in Fig. 3 has a width of $T = 300$ ps. This result is better than the state-of-the-art result reported in June 2005 in [6]. Such a short pulse is critical to the success of signal propagation study. We also achieved binary phase shift keying (BPSK) on this testbed.

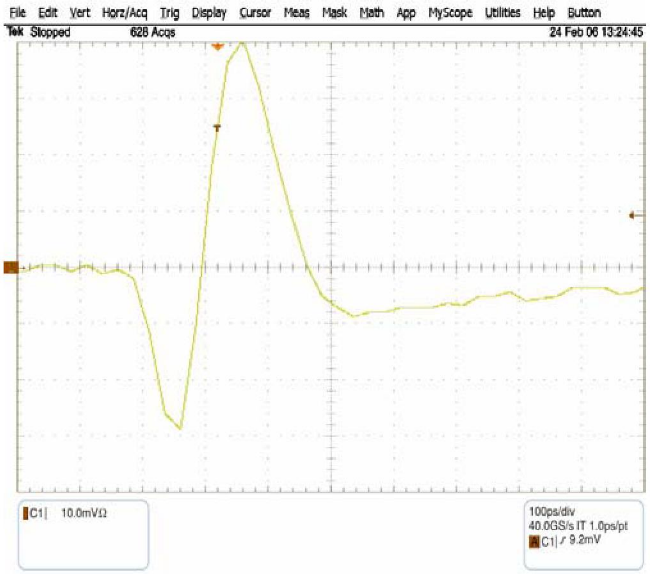


Fig. 3 The received signal in a lab. The transmitting antenna and the receiving antenna were 211 inches away from each other at the height of 44 inches.

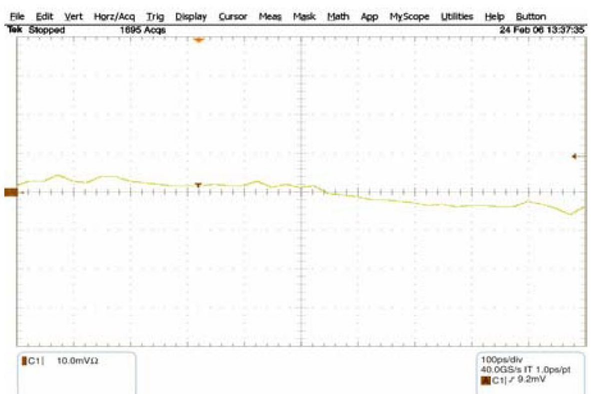


Fig. 4 The received noise when the transmitter was turned off.

III. CHANNEL SOUNDING

The UWB testbed has been applied to measure signal propagation in a 1999 Chevy Prism Sedan, with the hope to replace the water-tight twisted wires and connectors in the car.

Fig. 5 shows the received signal, when the transmitting antenna was placed on the rear left wheel of the Prism, and the receiving antenna was installed at the bottom of the engine compartment. The received signal was 76 mV peak-to-peak and less than 1.5 ns. This means 660 mega-pulses per second can be received without inter-symbol interference.

Fig. 6 shows the received signal when the transmitting antenna was placed on the rear right wheel of the Prism. The received signal was 117 mV peak-to-peak and approximately 3 ns. It means 330 mega-pulses per second can be received without inter-symbol interference. Comparing to the transmission from the rear left wheel, the transmission from the rear right wheel had 50% pulse rate reduction, which was caused by more paths introduced by a large piece of metal under the vehicle body right next to the rear right wheel.

Fig. 5 The received signal at the antenna under the engine compartment. The transmitting antenna was positioned on the rear left wheel.

We also measured the UWB signal propagation within the engine compartment. Fig. 7 shows a setup, the transmitting antenna on the right and the receiving antenna on the left. The received signal was shown in Fig. 7 when the hood was shut. There were 2 clear paths with 2.1 ns between the beginning of the first pulse and the end of the second pulse. One can conclude that when line-of-sight exists within the engine compartment, the UWB system can support the reliable transmission of 470 mega-pulses per second.

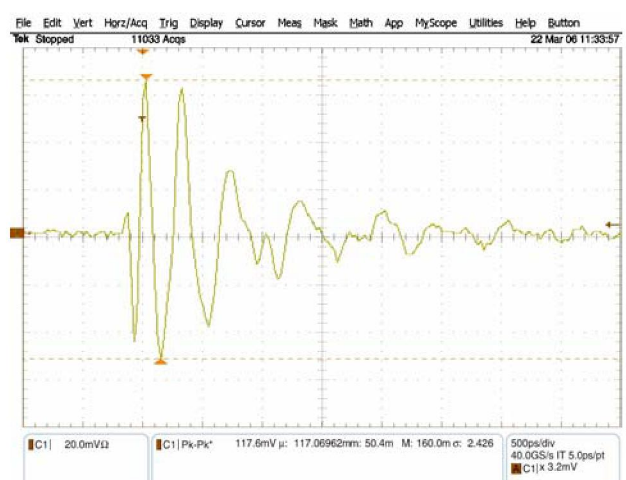


Fig. 6 The received signal at the antenna under the engine compartment. The transmitting antenna was positioned on the rear right wheel.

Fig. 8 shows the experiment setup where antennas were positioned deep in the engine compartment, and a large piece of metal shield originally installed by the auto manufacturer blocked antennas from seeing each other. When the hood was shut, the received signal was recorded and shown on the left, which was very strong with peak-to-peak as 50 mV and had many paths with a total duration of 20 ns. This means a total of 50 mega-pulses per second can be communicated without inter-symbol interference.

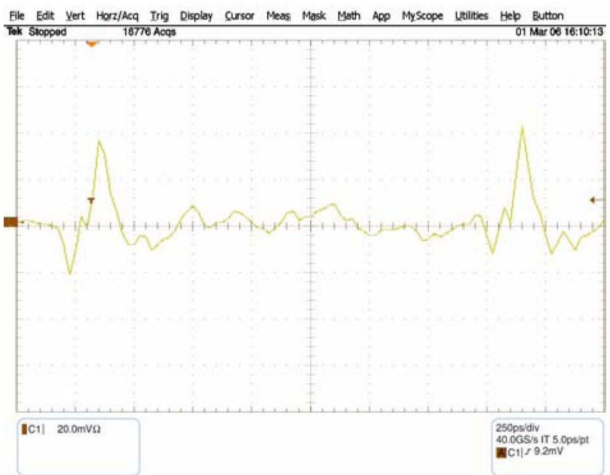
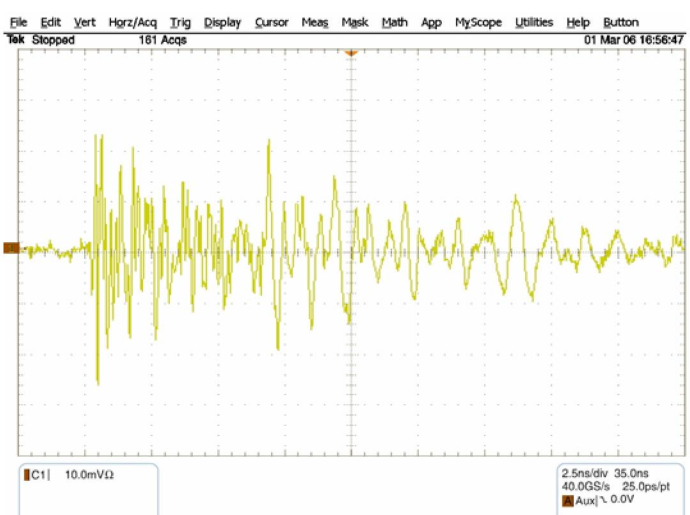


Fig. 7 The received signal in the Experiment 1 within the engine compartment. A line-of-site exists between antennas.



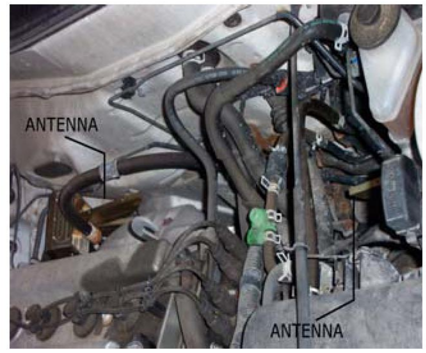
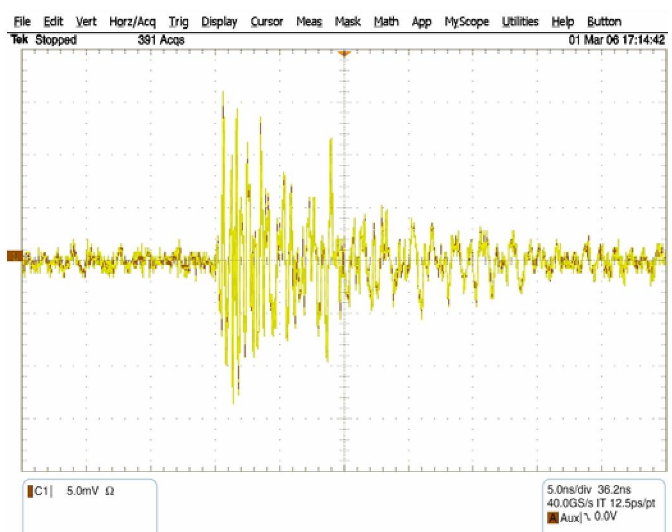


Fig. 8 The UWB Experiment 2 within the engine compartment. Antennas were installed deep in the engine compartment. A large piece of metal shield blocked antennas from seeing each other. There was no line-of-sight. The curve is the received signal. The picture is the experiment setup.

Fig. 9 shows the receiving antenna position in the Experiment 3 within the engine compartment. The transmitting antenna was located in the same location as in Fig. 8. The receiving antenna was positioned on a piece of original metal at the bottom of the car right next to the left front light. The engine sat between antennas which had no line-of-sight. This represents the worst blocking within the engine compartment for the vehicle. The received signal with the hood shut was 30 mV peak-to-peak and 20 ns for many paths. The received signal has the same duration in time as the duration of the received signal for the Experiment 2, while the received signal is a little weaker than that in the Experiment 2. The weaker signal was caused by the engine as a much larger blockage.



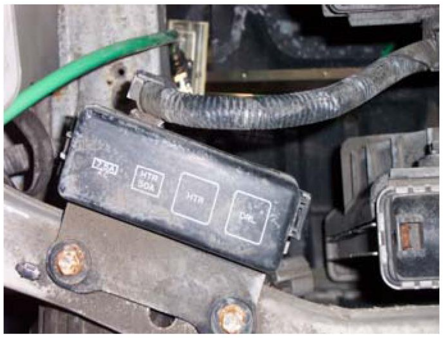


Fig. 9 The UWB Experiment 3 within the engine compartment. The receiving antenna connected to the green cable and placed at the front right corner of the engine compartment is shown on the right. The curve is the received signal. The picture shows the transmitting antenna position.

IV. CONCLUSIONS

Summarizing the data collected for a 1999 Chevy Prism Sedan using UWB channel sounding, one can conclude:

1. Communications between a transceiver at the bottom of the engine compartment and rear wheel speed sensors can be achieved at 330 mega-pulses per second using UWB technology without inter-symbol interference;
2. When the hood is shut, UWB communications within the engine compartment can achieve 476 mega-pulses per second when there is a line-of-sight, or 50 mega pulses per second when there is no line-of-sight.
3. The received signals for UWB communications within the vehicle are very stable, and have negligible fading. Pulses traveled through different paths are distinct in the received signals. In other words, the UWB technology has resolved mutipath.

Therefore, UWB can provide sufficiently high data rate for hundreds of wireless sensors in future automotive vehicles. The negligible fading in the received signals makes it much easier to design transceivers with low cost and low complexity.

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