60GHz Radio Hose for Wireless Harness Communication Systems

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***Abstract*— In order to lower car fuel consumption and increase communication capacity, a wireless harness communications system that uses metal coated plastic/rubber hose (radio hose) as the communications channel is proposed. Measurements results show that the proposed system reduces conventional harness weight to 1/10, and increase reliability even if the hose is cut and/or pinched. This indicates a possibility for wireless communications systems to be adopted not as a soft safety system but a hard safety system for the first time.**

Keywordst— Sesor; millimeter wave communications; wireless communications; automobiles, harness

I. INTRODUCTION

Since the weight of wire harnesses in cars has been increasing due to increase of number of Electronic Control Unit (ECUs), there is strong need for "harness weight saving". A typical wire harness weighs around 30 to 50 Kg and various weight saving approaches have been proposed [1]. Conventional wire harness communication systems use copper wires, to interconnect the many ECUs. Since the number of such units continues to increase with the rapid adoption of hybrid and electrical systems, conventional wire harness systems are becoming excessively complex and heavy. Another trend is the increase use of intra-car multimedia systems that demand high data rates. In "intra-car communication systems", there is not only front display for car navigation systems but also are many multimedia monitors for TV and movies. In order to realize these applications, a high data rate communication channel is also required in vehicles [2-3]. Currently, USA automobile regulation requires tire pressure monitor. This has been done by using Bluetooth technology and it is so called "soft safety" application where some erroneous transmissions are allowed. Meanwhile, engine and brake control systems cannot allow erroneous transmission at all and use wired connections. They are called hard safety and not even short term disruption is permitted. This is naturally the only choice given by current technology. To meet these requirements, the "wireless harness communication system with radio hose" has been proposed. The proposed radio hose is a hybrid of wire and wireless communications. This system uses a "radio hose" which is lighter than conventional wire harnesses while offering the wide bandwidth needed for multimedia services, the robustness demanded by the control systems, and multiplexing transmissions by a single radio hose. The radio hose is made by thin metal coated low dielectric material, such as polyolefin whose weight is much lighter than wire harness. Since the proposed radio hose aims to replace the current wired harness, we name the radio hose system as "wireless harness". The proposed system has high reliability since communication remains possible even if the hose is cut or pinched. Metal coated hose offers high immunity from electromagnetic interference as well. The proposed system offers light weight, wide bandwidth, and highly reliable wireless harness systems. Since conventional wired connects fail once a wire or connector fails, the proposed system offers higher communication reliability and well suits "hard safety" applications. The proposed system is assumed to use 5 and 60GHz unlicensed bands. Although all wireless transmissions are contained within the hose, there is no need to use unlicensed bands. We have selected these bands since relatively cheap transceivers are available for 5 and 60GHz band applications. When transceiver physical size is considered, the 60GHz band is promising, while the 5GHz band offers long range communications. In our previous work [1], the large radius hoses (25-40mm) were found to be suitable with low loss for wireless harness communication systems. In order to replace the current wired harness (with about 6.5 mm in diameter), however, this paper focuses on small radius hoses, such as 6.5 mm in diameter.

This paper shows that the transmission loss of a 4m length hose is estimated 39.4dB, which is 40.6 dB lower than the loss of over-the –air transmission (80dB) [4] and a delay spread is as small as 0.2ns, which is small enough for effective communications without equalizers and no equalizers will contribute to realize low latency systems. Although this paper describes 3 Gbps transmission systems mostly, a variety of transmission rates, such as 1 Gbps or lower are possible supported by IEEE802.15.3c standard. We used the measured results to design the channel model and BER simulations of both control and entertainment signal transmission channels. The simulation results show BER penalty is less than 1dB with Forward Error Correction (FEC). Since these results show that there is no need to use Orthogonal frequency-division multiplexing (OFDM), essential if the delay spread is significant, the proposal offers high speed communication systems with single carrier links and simple equalizers.

This paper is organized as follows. Section II describes the structure and basic performance of the proposed wireless harness communications system. Section III describes its reliability. Section IV describes multi channel communication performance. Section V summarizes our work on wireless harness communication systems.

II. WIRELESS HARNESS COMMNICATION SYSTEMS

As shown in Figure 1, the model considered here consists of control systems to send control signals from sensors, and entertainment signal transmission systems. The central hub is assumed to be the car navigation system. For general vehicles, the maximum communication length is estimated to be 4m. Because 5GHz communication systems are suitable for big vehicles like trucks, this paper targets the 4m wireless harness performance since this will be the most common application.

The wireless harness is a plastic hose with conductive coating. Our previous research examined a wireless harness with large radius (ϕ=40mm) and proved a possibility of low loss and highly reliable transmission over wireless harness. Given the severe space constraints of modern vehicles, 40mm radius hose is not so practical and this paper examines radio hoses with smaller radius.

Figure 2 shows trial small radius wireless hose appearance and its cross section view. Its outside diameter is 6.5mm and inside diameter is 6mm. The hose made of polyolefin has a relative permittivity of 2.3-2.4. As shown in Figure 3, its transmission loss is 16.5dB smaller than non-coated hose. This shows that wireless harness is suitable for establishing practical communication channels. Table I compares the performance of this small radius hose with the performance of the large radius hose measured in previous work [1]. In table I, the delay spread is also improved by metal coating. As for the latency, we do expect much shorter than the current wired harness since the transmission rates of the proposed systems are 10^4 times faster than the current one, however, we need to wait for further detailed analysis.

In order to clarify wireless harness communication capacity, we measured transmission losses and delay spreads of 1, 0.5, and 0.25m hoses. The measurement system is shown in Figure 4 and results are shown in Figure 5. The transmission loss is calculated by (1)

$$\text{Total transmission loss} = \text{Transmission loss constant} \times \text{Hose length} + \text{Antenna conversion loss} \times 2 \qquad (1)$$

From (1) and Table II, the transmission constant is 8.2dB/m, antenna conversion loss is 3.3dB, and the estimated transmission loss is 39.4dB. By assuming the sensitivity of a 3Gbps receiver is - 55dBm at 60GHz (typical sensitivity defined by IEEE802.11ad standard), and maximum transmission power is 10dBm (typical transmission power of Transmitter modules in unlicensed bands), the margin of the small radius wireless harness for 3Gbps communication is around 35dB. In IEEE 11ad standards, multiple communication speed is supported. The assumed systems are based on IEEE 802.11.ad standard which supports High (more than 3Gbps) and low (1Mbps) speed communication. In these standards, the communication is possible if the received signal level is higher than the receiver's sensitivity.

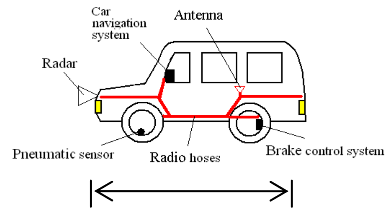

Fig.1 Wireless harness for vehicles

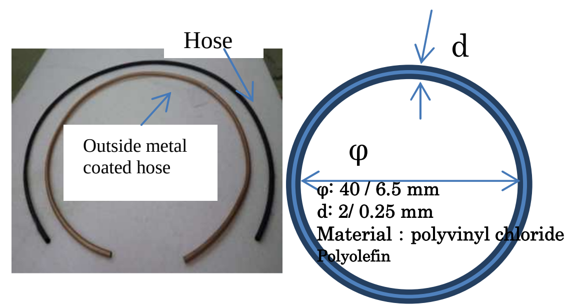

Fig.2. Metal coated hose

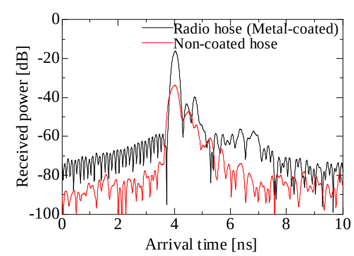

Fig.3 Transmission peformance of wireless harness

TABLE I. RADIUS COMPARISON OF WIRELESS HARNESS

	Transmission Loss@1m	Delay spread@1m
Small radius(ϕ =6.5mm) wireless harness	14.8	0.08
Large radius(ϕ =40.0mm) wireless harness	31.3	0.16

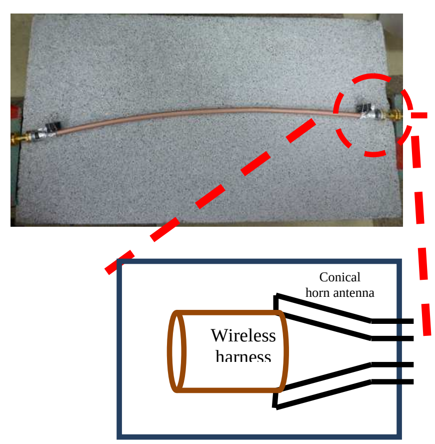

Fig.4 Measurement setting

Since IEEE11.ad standard supports high and low speed communications and our proposed systems work in these standards, the proposed systems cover from low speed to high speed communications.

III. RELIABILITY OF WIRELESS HARNESS

A. Immunity to engin noise

In order to clarify interference mitigation performance of the small diameter hose to engine noise, penetration loss of radio hose has been measured. Hose material is Polyvinyl chloride for this test and 2 horn antennas were set facing each other and the wireless hose was set on between them. For comparison, metal coated and non-coated hose penetration loss was measured. Measured results are shown in Figure 5. Non-coated hose penetration loss is matched with the free space loss, while the coated hose had 30dB higher penetration loss. Since intra-car noise in the microwave band and millimeter wave band is small, the 30dB penetration loss shows the proposed wireless harness has good noise immunity and can realize highly reliable communications

B. Communications continuity against radio hose cut and pinching

Our previous study found that the hose bend effect was less than 4dB loss increase, i.e., negligible for 3Gbps communications. This paper examines hose cut and pinching.

The definition of cut length is shown in Figure 6. The cut loss for lengths of 0, 1, 2, 4, and 5cm were measured as shown in Figure 7. The loss increases with cut length; it is 15dB for 5cm cut length.

Pinch depth is defined in Figure 8. Transmission loss was measured for pinch depths of 0, 2, 4, and 6mm as shown in, Figure 9. The loss increases with pinch depth and is less than 20dB for depth of 6 mm – 100 % pinched case. Since wireless harness has 30dB margin for 3Gbps communications as shown in the previous section, the wireless harness remains operational even if radio hose is cut and separated by 5 cm or radio hose is pinched virtually flat.

TABLE II. LOSS AND DELAY SPREAD VS. HOSE LENGTH

Hose length [m]	Transmission loss [dB]	Delay spread [ns]
1	14.8	0.08
0.5	10.7	0.1
0.25	9.4	0.2

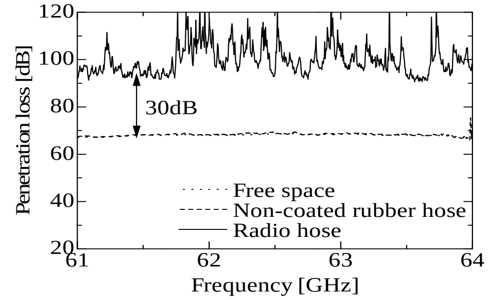

Fig.5 Penetration loss peformance of radio hose

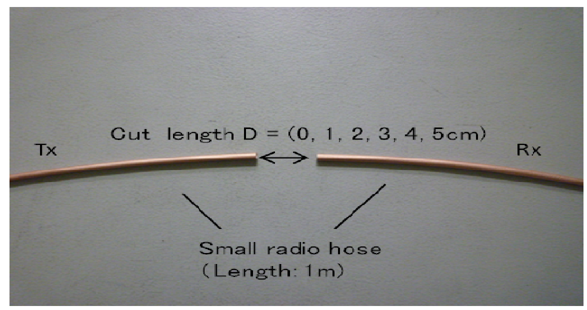

Fig.6 Cut length definition

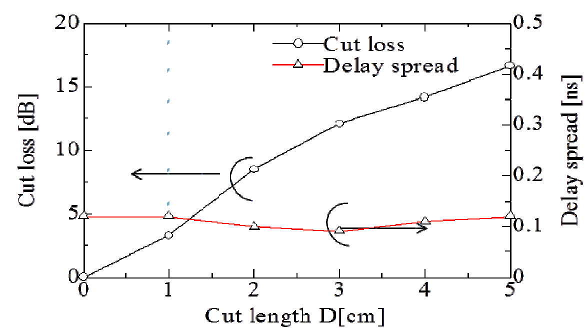

Fig.7 Measured cut loss results

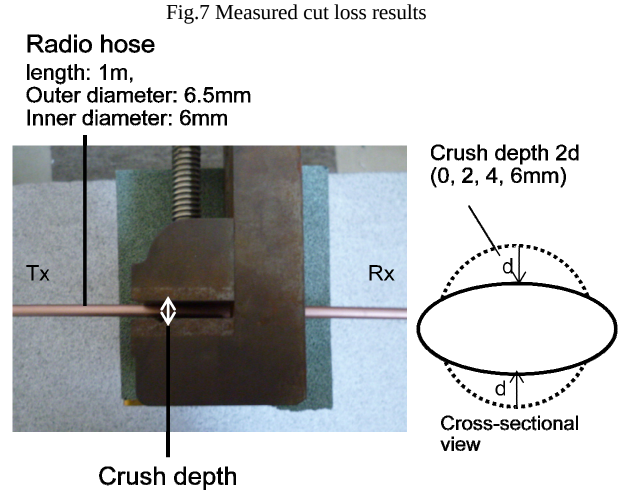

Fig.8 Pinch depth definition

IV. MULTI CHANNEL COMMUNICATIONS

Wireless harness communication systems can realize multi point communications. A typical system configuration is shown in Figure 10. Tx and Rx1 antennas are conical horn antennas with 13dBi gain with 45HPBW while Rx2 antenna is a monopole antenna with a 1.6dBi Omnidirectional gain. The monopole antenna consists of semirigid cable. Tx and Rx1 use circular polarization while Rx2 uses vertical polarization. The possible situations are Sub Length Communication (SLC) which connects the inserted antenna to the inserted antennas, and Whole Length Communication (WLC) where hose ends are directly connected. SLC measurement results are shown in Table III. SLC transmission loss at 4m is 54.5dB by (1). When transmission power is 10dBm, received power at SLC antenna is -44.5dBm which is higher than receiver sensitivity for 3Gbps communication in 60GHz band. WLC measurement results are shown in Table IV. The increase in WLC transmission loss due to by SLC antenna insertion is less than 0.3dBe. Thus, WLC still has 30dB margin for 3Gbps communication in the 60GHz band.

V. CONCLUSION

This paper proposed a wireless harness system consisting of metal-coated plastic hose (6.5 mm OD) to replace wire harness in automobiles. Measurements showed that the proposed system can realize low loss, small delay spread, and high reliability intra-car communication systems. The proposed system has the following features. Transmission loss of a 4m wireless harness is 39dB, 41dB smaller than free space loss. For the typical receiver sensitivity of 3Gbps communication, the system margin is around 25dB. The delay spread under the condition of hose cut or pinch is less than 0.3ns and loss is smaller than the margin. In multi channel transmission, the loss increase is less than 19dB, which again is smaller than wireless harness communication margin.

These measurement results confirm that the proposed wireless harness is a good candidate for future, high efficiency, intra-car communication systems.

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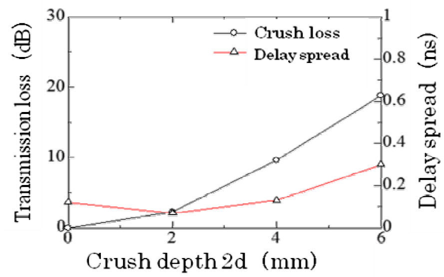

Fig.9 Measured pinch depth results.

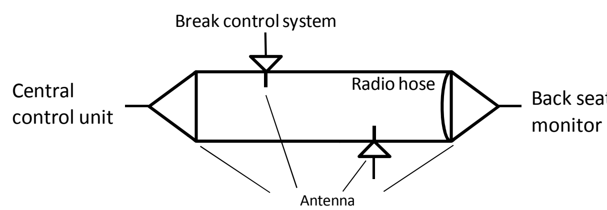

Fig.10 Multi channel communications

TABLE III. SLC TRANSMISSION PERFORMANCE

Hose length[m]	Transmission lossd [m]	Delay spread [ns]
0.25	22.6	0.32
0.5	25.4	0.27
0.75	30	0.28

TABLE IV. WLC TRANSMISSION PERFORMANCE

Hose length[m]	Transmission loss [dB]	Delay spread[ns]
0.75 (no-SLC antenna)	13.8	0.14
0.25	14.2	0.14
0.5	14	0.14
0.75	14.1	0.13