Investigation on the Influence on VDSL Transmission Speed and Radiated Electric Field Strength due to Unbalance in Metallic Communication Lines

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***Abstract*— VDSL can provide low-cost broadband services by transmitting high frequency signals using existing metallic communication lines. However, because metallic communication lines were not originally installed with the intention of transmitting high-frequency signals, they may suffer from unbalance, which can affect the VDSL transmission speed and radiated electric field strength. In this paper, we report on an investigation into the influence of the Longitudinal Conversion Loss (LCL) of metallic communication lines on the VDSL transmission speed and radiated electric field strength. The results show that the degradation of the LCL caused by the capacitance between a communication line and the earth does not cause a reduction in the transmission rate. However, the electric field strength was increased by up to about 37 dB. In teh case of inductance, the increase in the LCL caused by the inductance of a communication line caused both a reduction in transmission speed and an increase in radiated electric field strength of up to about 42 dB.**

Key words: LCL, VDSL, transmission speed, electric field strength

I. Introduction

Recently, the rapid spread of the use of the internet has promoted the use of high-speed communication services. In particular, in collective housing such as apartment blocks, a Very high speed Digital Subscriber Line (VDSL) service has been deployed; this uses optical fiber to transmit signals from an NTT telecommunication center to a common use space in the apartment block, and uses metallic communication cables from the common use space to each individual apartment [1]. This reduces the attenuation of signals due to the transmission distance, which is a characteristic of ADSL services, and enables 100 Mbps transmission speed both upstream and downstream.

However, because VDSL transmits signals using a frequency band of 640 kHz-30 MHz on existing metallic communication lines, high-frequency signals may be attenuated. The longitudinal conversion loss (LCL) of the communication lines is about 40 dB at 30 MHz and cables must be configured and installed properly in order to transmit signals stably and at high-speed. However, a difference in the capacitance of the two conductors, caused by the fact that one runs closer to earth, and differences in inductance, caused by the fact that one conductor may be twisted more than the other at a connection point, may change the LCL. This may affect both the transmission speed and the radiated electric field strength.

Studies of the influence that PLC signals have on a VDSL signal caused by the coupling of in-house power line and communication cables have been undertaken [2]. In addition, the influence on the noise immunity of VDSL due to variations in the electrical characteristics of premise cables have been examined [3]. However, when VDSL signals are transmitted via metallic communication lines, the influence on the VDSL transmission speed and radiated electric field strength of variations in the LCL of the communication line has not been examined.

In this paper, we consider the effect of lumped components simulating increased parallel capacitance and series inductance, as factors causing degradation of the LCL. We undertook experiments to clarify the relationships between the LCL, the transmission speed of VDSL signals and the radiated electromagnetic field strength.

II. Experiments

In this section, we investigate the relationships between the LCL, transmission speed of VDSL signals and radiated electromagnetic field strength when parallel capacitance and series inductance are inserted in one conductor of the transmission line.

A. Characteristics of transmission line

1) Experimental Methodology

In this section, the LCL of communication lines was measured to clarify the variation of LCL when various magnitudes of parallel capacitance and series inductance were inserted in one conductor. The LCL is defined in the following expression [4]:

$$LCL = 20\log\left|\frac{(v_{i1}+v_{i2})/2}{v_{i1}-v_{i2}}\right| \quad (1)$$

where, the two conductors are defined as Line 1 and Line 2.

v_{i1}: the difference in voltage between the earth and Line 1 at the signal input terminal.

v_{i2}: the difference in voltage between the earth and Line 2 at signal input terminal.

The system used to measure the LCL is shown in Fig. 1. As shown in this figure, a network analyzer was used to make the measurements. A balun was used to match the 50 Ω characteristic impedance of the network analyzer to the 100 Ω of the communication line. The same voltage was applied to the two conductors (Line 1 and Line 2) at the common mode input terminal. Then, the voltage between the two conductors was measured at the differential mode output terminal.

The conductors were made of copper, were 0.5 mm in diameter, and were located parallel, 1mm apart. They were located 15 cm above the ground plane, and terminated in 100 Ω.

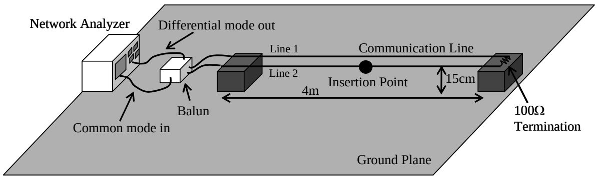


Fig. 1 The measurement setup

In a real situation, the distance between the two conductors and the earth is not constant, and the capacitance between each of the two conductors and the earth is not same. In this experiment, this phenomenon was simulated by inserting a capacitance between one conductor and the earth as shown in Fig. 2.

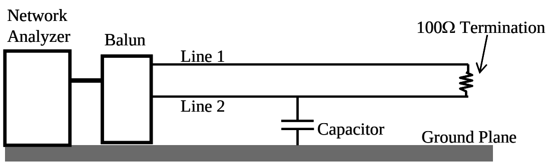


Fig. 2 Measurement setup for inserting capacitor

Moreover, the inductance of a conductor may be increased when it is twisted by hand at a connection point. In this experiment, this was simulated by inserting an inductance in one of the conductors.

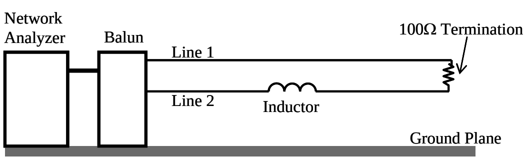


Fig. 3 Measurement setup for inserting inductor

The line length was 4 m, and the insertion point of the capacitor and inductor was at the center point of the line. The values of capacitor and inductor which were inserted are shown in Table 1. Also, these values that cable length is 100 m are calculated by referring [5]. The typical values used for the capacitor and inductor were 0.001 μF and 10 μH respectively. Moreover, to evaluate the characteristics quantitatively, extreme values of capacitor and inductor were investigated, above and below these typical values.

TABLE 1. VALUES OF CAPACITOR AND INDUCTOR USED

Capacitor	10 pF, 100 pF, 0.001 μF, 0.01 μF, 0.1 μF
Inductor	0.1 μH, 1 μH, 10 μH, 100 μH, 1000 μH

2) Experimental Results

The measurement results, when a capacitor was inserted at the center point of one conductor, are shown in Fig. 4. In this figure, “normal” corresponds to the case where no additional capacitance was inserted.

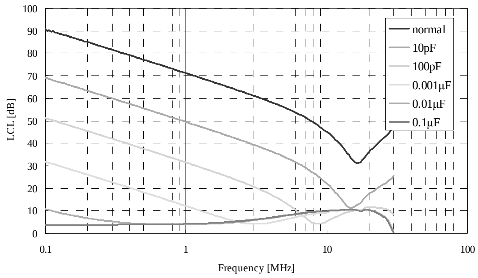


Fig. 4 LCL for different values of inserted capacitance

Fig.4 shows the following.

- A tenfold increase in capacitance results in a 20 dB reduction in the LCL.
- For a given value of capacitance, the LCL reduces with frequency by about 20 dB per decade.

Thee minimum or null points of the LCL shown in Fig. 4 shows are caused by the resonance of the line. For comparison, when the length of the line was reduced to 2 m and then 1m, the frequency of the LCL null point increased in inverse proportion.

The measurement result when an inductance was inserted at the mid-point of one conductor is shown in Fig. 5.

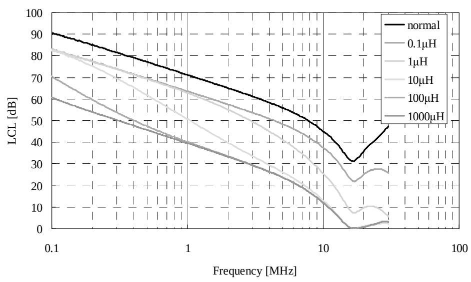


Fig. 5 LCL for different values of inserted inductance

Fig.5 shows following things.

- The LCL degrades as the inductance is increased.

- For 0.1 μH and 1000 μH, the LCL reduces with frequency at 20 dB/ decade. For other (intermediate) values of inductance, the LCL lies between the LCL characteristics of 0.1 μH and 1000 μH.

As with the capacitance, the frequency of the minimum or null points shown in Fig. 5 varied in inverse proportion to the length of line.

B. The Measurement of Transmission Speed

1) Experimental Methodology

In the real situation, if the immunity was decreased by degrading of the LCL, the transmission speed might be affected. In this section, we investigate the influence on the VDSL transmission speed of the variation of LCL measured in the previous section.

The measurement setup is shown in Fig. 6. As shown in Fig. 6, the VTU-O and VTU-R are connected by a pair of conductors. The transmission speed of VDSL and DMT carrier bit-rate distribution, when a capacitance and an inductance were inserted at the center point of one of the conductors, were measured via the control PC. The conductors were again located 15 cm above the ground plane.

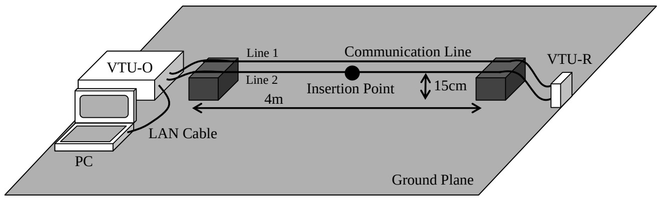


Fig. 6 Measurement setup for transmission speed

2) Experimental Results

The measurement results are shown in Table 2 and Table 3. Here the measurement results for transmission speed are expressed as the ratio (percentage) of the speed when the lumped component was inserted to the speed when it was not inserted.

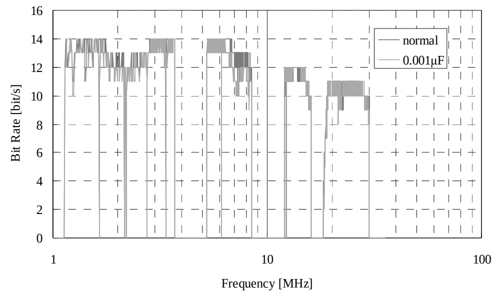
TABLE 2. EFFECT ON TRANSMISSION SPEED OF INSERTING CAPACITOR

	10 pF	100 pF	0.001 μF
Uplink [%]	100	100	100
Downlink [%]	100	100	98.78

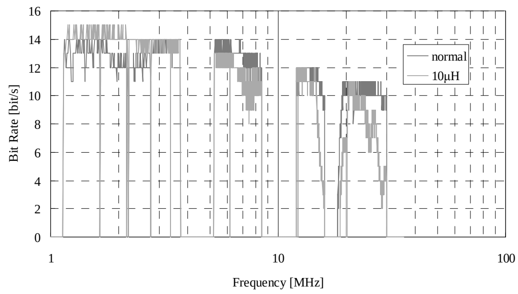
TABLE 3. EFFECT ON TRANSMISSION SPEED OF INSERTING INDUCTOR

	0.1 μH	1 μH	10 μH
Uplink [%]	100	100	69.25
Downlink [%]	100	100	91.13

Corresponding to the tables above, the DMT carrier bit-rate distribution of VDSL signals when a capacitance (0.001 μF) and an inductance (10 μH) were inserted, are shown in Fig. 7.



(a) Bit-rate frequency distribution when capacitance inserted



(b) Bit-rate frequency distribution when inductance inserted

Fig. 7 Measurement Result of Bit Rate Distribution

From Table 2 and Fig. 7 (a), when a capacitor of 0.001 μF was inserted, the LCL was degraded by 60 dB compared with the normal value. However, the transmission speed was reduced by only about 1 % and only in the uplink. It is clear from the DMT carrier bit-rate distribution (Fig. 7(a)) also that the transmission rate was slightly reduced by the insertion of capacitance into the line.

From Table 3 and Fig. 7(b), when a inductor of 10 μH was inserted, the LCL was degraded on average by 30dB compared with the normal value. The transmission speed was reduced by about 30 % in the uplink and about 10 % in the downlink. It is clear from the DMT carrier bit-rate distribution (Fig. 7(b)) that the transmission rate was reduced especially at higher frequencies. This is because the impedance of the lines has increased as a result of inserting the inductance, and so the signal is attenuated.

C. Measurement of Electromagnetic Field Strength

1) Experimental Methodology

The LCL is the ratio of the normal-mode voltage to the common-mode voltage. So, a reduction in the LCL corresponds to a relative increase in the common-mode voltage. When a common-mode voltage is generated, a common-mode current is generated and propagates on both conductors in the same direction. Therefore, the communication line radiates an electromagnetic wave as an antenna, and this may influence wireless communication services and electrical equipment that use the same frequency band as the VDSL service. So, measurements were made of the variation in electric field strength radiated from the communication line when VDSL signals were transmitted.

This was then compared with the target level of ITU-T recommendation K.60 which concerns radiated electromagnetic waves from communication lines in case of radio interference [6].

The measurement setup is shown in Fig. 8. The VTU-O and VTU-R are connected with a pair of conductors (L=4 m) and VDSL signals were transmitted. In this situation, when the different values of capacitance or inductance shown in Table 2 and Table 3 respectively were inserted, the electric field strength was measured with the loop antenna and the spectrum analyzer. The conductors were located 15 cm above the ground plane, and the loop antenna was located 1 m from the centre-point of the communication line, and its height was 1 m. These measurements were conducted in an anechoic chamber.

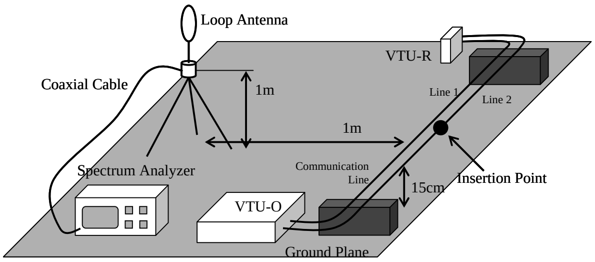
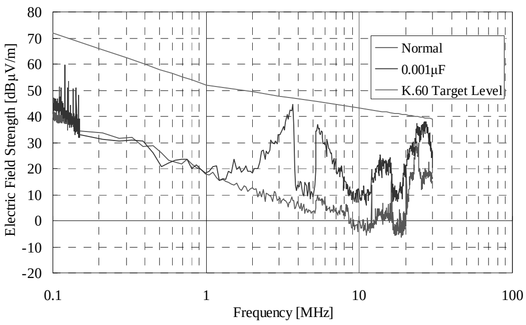


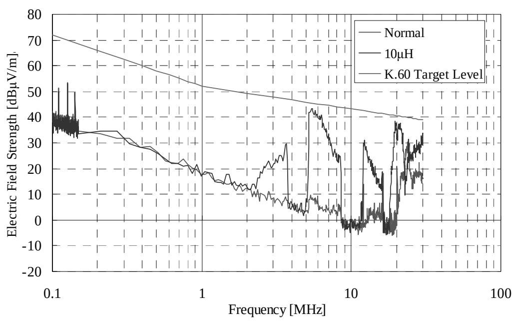
Fig. 8 Measurement setup for electric field strength

2) *Experimental Results*

The measurement results are shown in Fig. 9; "normal" in this figure again indicates the case in which no additional component was inserted. The electric field strength was normalized to a distance of 3 m as specified in K.60.



(a) Insertion of capacitance



(b) Insertion of inductance

Fig. 9 Measurement results for electric field strength

From Fig. 9, when a capacitance (0.001 μF) was inserted, the electric field strength increased by up to about 37 dB. When an inductance (10 μH) was inserted, the electric field strength increased by up to about 42 dB. However, both measured values are less than the target level of K.60. These results show that degradation of the LCL increases the radiated electric field strength.

III. CONCLUSION

This paper reports on experimental investigations into the LCL of communications lines used for VDSL, and the influence of the LCL on the transmission speed of the VDSL links and the radiated electric field strength. The key conclusions are as follows.

- When various values of capacitance were inserted into the communication line, the LCL was found to decrease by about 20 dB for each tenfold increase in inserted capacitance. However, no reduction in VDSL transmission speed was caused. Insertion of a capacitance of 0.001 μF caused the radiated electric field strength to increase by up to 37 dB at the frequency most affected.
- Insertion of a 10 μH inductor caused degradation of LCL of about 20 dB. Under these conditions, the VDSL transmission speed was reduced by about 30 % in the uplink and about 9 % in the downlink. Insertion of an inductance of 10 μH caused the radiated electric field strength to increase by about 42 dB at the frequency most affected.

ACKNOWLEDGMENTS

This study is grant-aided from the subsidized institution of Strategic Information and Communications R&D Promotion Program (SCOPE) of the Japanese Ministry of Internal Affairs and Communications.

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