# Influence of Different Configurations of Premises Cable on the Interference Immunity of VDSL Systems

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***Abstract*—The link between VTU-O and VTU-R is influenced by electromagnetic interference induced into the premises cables in customers' premises. The influence of different configurations of premises cables on the immunity of VDSL systems is investigated in this paper. The results show that when premises cable is bent back and forth or in looped in a coil, the longitudinal conversion loss (LCL) is greater than when the cable is laid in a straight line. There is a correlation between the value of induced voltage which causes the link to fail and the LCL, regardless of the configuration of the premises cable, because a decrease in LCL results in an increase in the strength of the differential-mode interfering signal.**

## I. INTRODUCTION

The VDSL service[1] has been advanced because it allows the provision of an FTTH service at low cost, by making use of copper cables in customers' premises. The premises cables are used for the short links between the VDSL Transceiver Unit in the Optical Network Unit (VTU-O) and the VDSL Transceiver Unit - Remote Terminal (VTU-R) to connect the equipment located in a common shared space in cluster housing to the terminals in individual residences. Although the maximum transmission rate of VDSL can reach 100Mbit/s, VDSL suffers from the fact that it is prone to electrical interference, which may be induced in the premises cables.

Investigations have already been carried out on the influence of electrical interference induced by power line communication (PLC) on the transmission characteristics of VDSL[2]. The influence of the longitudinal conversion loss (LCL) of premises cables on the immunity of VDSL systems has also been investigated[3]. However, although the influence has been investigated for a constant length of premises cable running in a straight line[3], the LCL of the premises cable in an actual installation, depends on the configuration of the cable (e.g., length, branching, and bending). Therefore, the influence of different configurations of the cable on the immunity of VDSL systems has not yet been established.

In this paper, we evaluate the LCL or transmission loss of premises cable for various configurations, and describe the relationship between the configurations of premises cables and the immunity of the link between a VTU-O and a VTU-R.

## II. VDSL SYSTEM

### A. VDSL system configuration

Fig. 1 shows the general configuration of a VDSL system. The link between a telecommunication center and a VTU-O located in the shared common space of cluster housing is provided by optical fiber cables, while the premises links between the VTU-O and the VTU-Rs are provided by copper premises cables. VDSL possesses the advantage that it allows an FTTH service to be introduced at a moderate price because it does not require the installation of new optical fiber cable on customer premises. However, the use of metallic cables requires consideration of the transmission loss, the impedance mismatch, and the unbalance in the cables. The influence of interfering sources such as radio waves from broadcasting services or ham radio operators should be also considered.

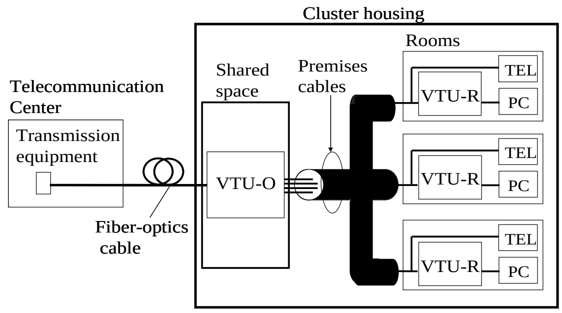



Fig. 1 Configuration of VDSL system

### B. Premises cable

Fig. 2 shows a star-quad cable, which is the most popular type of cable used in customer premises in Japan. A quad consists of four insulated core wires, which are twisted together, opposite wires forming a pair (e.g. L1 and L2). A star-quad cable of 10 pairs consists of 5 quads twisted together.

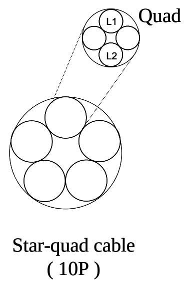



Fig. 2 Structure of star-quad cable

## III. CHARACTERISTICS OF PREMISES CABLE

The LCL of premises cable is correlated with the immunity to interference of the link between the VTU-O and the VTU-R, as described in [3]. However, since premises cables are wired with various layouts, the LCL varies according to the configuration (e.g., length, branching, and bending).

As the star-quad cable is the most popular premises cable in Japan, we have evaluated the LCL of this type of cable in order to investigate the relationship between the cable configuration and the immunity to interference of the link between the VTU-O and the VTU-R. As the transmission loss of the cable also may also change according to the configuration of the cable, we evaluated the transmission loss as well as the LCL.

*A. Measurement of LCL*

LCL is defined as equation (1)[4].

$$LCL = 20 \log_{10} (E_L/V_T) \quad [dB] \quad (1)$$

where, $E_L$ is the voltage of a longitudinal source injected into two core wires, L1 and L2, and $V_T$ is the transverse voltage between L1 and L2.

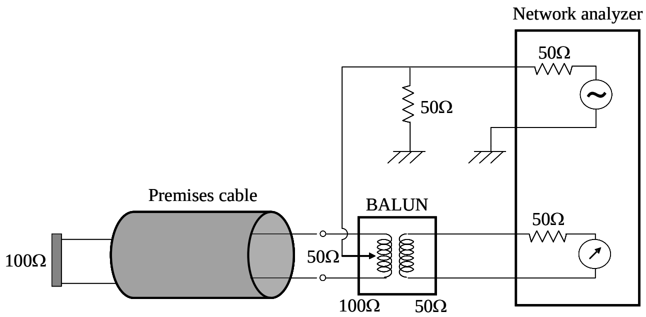



Fig. 3 Measurement system for the LCL

Fig. 3 show the measurement system used for determining the LCL based on ITU-T Rec. G.117[4]. We measured the LCL of the premises cable for five different configurations. The first case, shown in Fig. 4, is for a straight cable. The second and third cases, shown in Fig. 5 (a) and (b), are for situations where the cable is bent back and forth in a repeated, periodic fashion. The forth and fifth cases, shown in Fig. 6 (a) and (b), model situations where the cable is bent into a coil or loop. In each case the length of the sample of star-quad cable was 10 m.

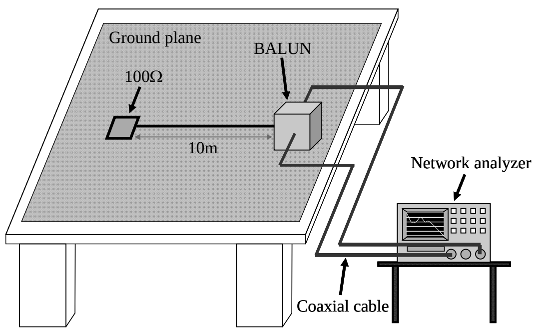
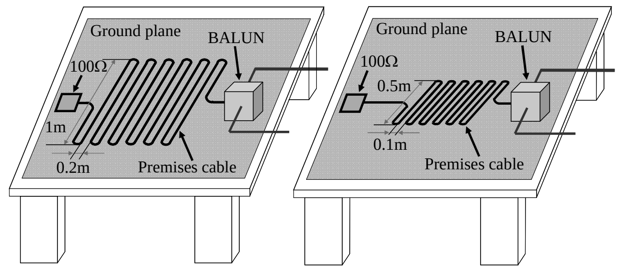
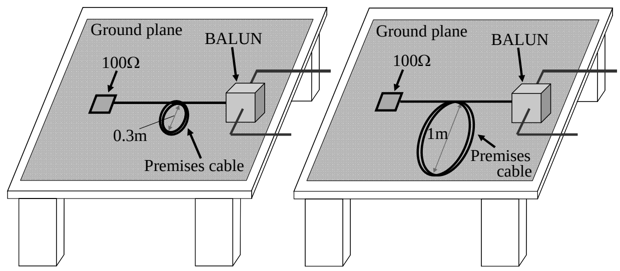



Fig. 4 Measurement setup for case 1




(a) Case 2 (b) Case 3

Fig. 5 Measurement setup for cases 2 and 3




(a) Case 4 (b) Case 5

Fig. 6 Measurement setup for cases 4 and 5

Fig. 7 shows the measured LCL for cases 1 to 5. As shown in Fig. 7, case 1 gave the worst performance of the LCL below 2 MHz. Cases 4 and 5 yielded almost identical LCL characteristics. Below 2 MHz, the LCL of Cases 4 and 5 was about 10dB higher than that of Case 3, which in turn was 10dB higher than Case 2.

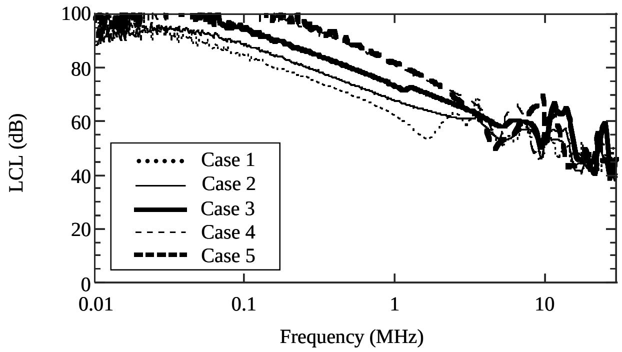



Fig. 7 Measured LCL for cases 1 to 5

*B. Measurement of transmission loss*

Fig. 8 shows the test set-up used for the measurement of the transmission loss of the star-quad cables. The transmission loss was measured for the same 5 configuration cases as were used for the measurement of LCL.

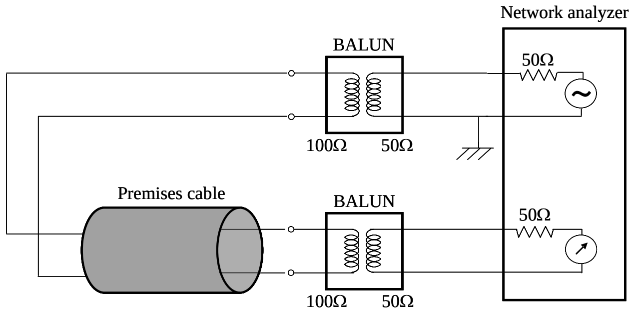



Fig. 8 Transmission loss measurement system

Fig. 9 shows the measured transmission losses for cases 1 to 5, and it may be seen that the transmission loss characteristic was almost identical for all cases. Although the different configurations gave different LCL characteristics, they gave virtually identical characteristics of transmission loss.

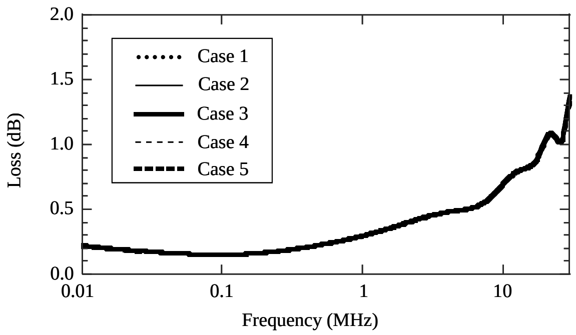



Fig. 9 Measured transmission loss for cases 1 to 5

## IV. INFLUENCE ON IMMUNITY OF VDSL SYSTEMS

The method of testing for immunity against conducted disturbances induced by continuous radio frequency (RF) fields for telecommunication equipment is defined in IEC 61000-4-6[5], and the requirements for telecommunication equipment and the test levels are defined in ITU-T Rec. K.43[6]. The influence of the difference in electrical characteristics of different configurations of premises cables on the immunity of the link between a VTU-O and a VTU-R was investigated by means of an immunity test based on the above international standards.

### *A. Measurement system for immunity test*

Fig. 10 shows the measurement set-up used for the immunity test for VDSL systems. As shown, the VTU-O was the equipment under test (EUT), and the premises cable was connected between the coupling and decoupling network (CDN) and the EUT. Here, Vc is the common-mode voltage at the test signal injection point, and Vn is the normal-mode voltage at the input of VTU-O.

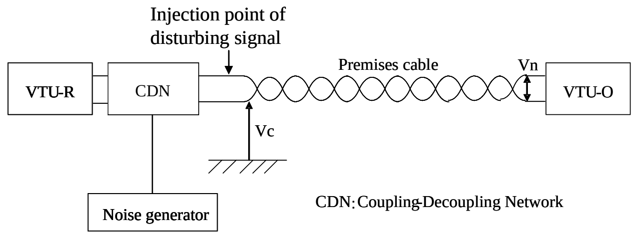



Fig. 10 Measurement system for immunity test

The main items of the specification of the VTU-O are shown in Table 1, and the conditions for the immunity test are shown in Table 2. As shown in Table 2, amplitude modulated (AM) waves at 23 frequencies were injected as the disturbing signal forming the continuous conducted RF signal at the injection point shown in Fig. 10. The frequencies of the disturbing signals were chosen to lie at approximately equal intervals on a logarithmic axis.

According to ITU-T Rec. K.43, a VTU-O is equipment for customer premises, and the test level of the continuous conducted RF signal is 3 V. In order to obtain the level of immunity to interference of the VTU-O, the disturbing signal was injected for 60 seconds, changing from 1 to 10 V in steps of 1 V.

TABLE I
MAIN SPECIFICATION FEATURES OF VTO-U

| | |
|---|---|
| The number of ports | 16 |
| Modulation / Duplex scheme | DMT modulation / FDD |
| Transmission rate (Max) | Downlink: 100 Mbit/sec |
| | Uplink: 100 Mbit/sec |

TABLE II
CONDITION FOR IMMUNITY TEST

| | | |
|---|---|---|
| Disturbing signal | Modulation type | AM |
| | Modulation depth | 80 % |
| | Modulation frequency | 1 kHz |
| Carrier frequency | 0.15,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0, 1.5,2.0,3.0,4.0,5.0,6.0,7.0,8.0,9.0,10.0, 15.0,2.0,30.0 (MHz) | |
| Injected voltage | 1 to 10 V (1V steps) | |
| Duration of injection | 60 seconds | |

In this paper, the link-down voltage is defined as the minimum injected common-mode voltage at the injection point in Fig. 10 which results in the link between the VTU-O and the VTU-R not being able to be established and operated satisfactorily. The influence of different configurations of premises cable on the immunity of the VDSL link was evaluated by comparing the link-down voltage for the different cases. Here, the conditions resulting in the VDSL system failing to perform satisfactorily are as follows.

- When a VTU-O or a VTU-R cannot recognize the communication control signal.

- When the communication signal between a VTU-O and a VTU-R loses synchronization.
- When the bit error rate of the communication signal between a VTU-O and a VTU-R exceeds a specified threshold level.

### *B. Measurement results of immunity test*

Fig. 11 shows the measured results of the link-down voltage for five cases. The link-down voltages when the cable was laid straight were the lowest among the five cases. The link-down voltages when the cable was bent in a coiled fashion (cases 2 and 3) were lower than those when the cable was bent back and forth repeatedly (cases 4 and 5) at some frequencies. This is because the level of the LCL was higher for cases 4 and 5, as shown in Fig. 7.

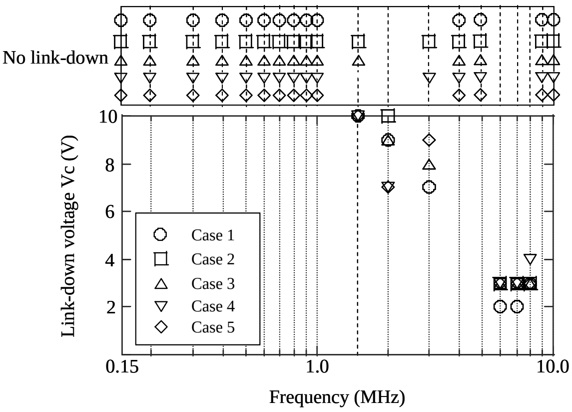


Fig. 11 Measured link-down voltage

Fig. 12 shows the relationship between the link-down voltages and LCLs at all the different frequencies. As the injected disturbing signal is transformed from common-mode to differential-mode by the unbalance of the cables when the level of the LCL was low, the link-down voltage is strongly correlated with the LCL for all cases. Fig. 12 also indicates that the differential-mode interfering signal had a great influence on the communication signal transmitted in differential-mode.

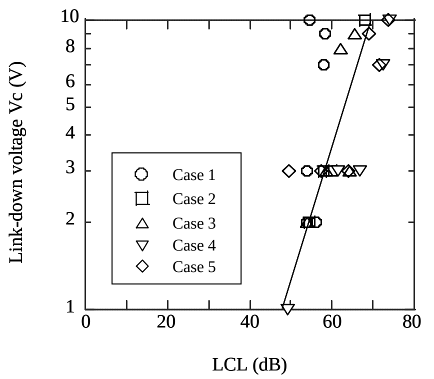


Fig. 12 Correlation between link-down voltage and LCL

Fig.13 shows the correlation between the link-down voltage and the normal-mode voltage, Vn, in Fig. 10; the link-down voltage is strongly correlated with the normal-mode voltage, Vn, for all cases. The result indicates possibility of an immunity test using the normal-mode disturbance waves when the representative value of the LCLs of the copper pair cables can be defined.

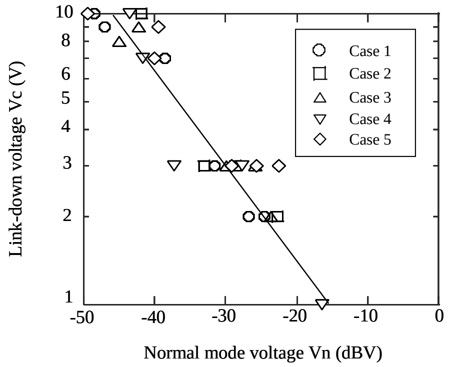


Fig. 13 Correlation between link-down voltage and normal-mode voltage

## V. CONCLUSION

This paper has described an experimental evaluation of the influence of different configurations of premises cable on the immunity to interference of VDSL systems. The results of the evaluation indicate the following.

- When premises cable is bent in either a back and forth or a coiled fashion, the LCL of the cable becomes higher than when the cable is laid in a straight line.
- Below 2 MHz, the LCL of the cable bent back and forth is about 10 dB higher than that of the cables bent in a coiled fashion.
- There is a correlation between the link-down voltage and the LCL of premises cables regardless of the configuration of the cables because a decrease in LCL results in an increase in the strength of the differential-mode interfering signal.
- There is also a correlation between link-down voltage and the differential-mode voltage at the input of VTU-O because a decrease in LCL means an increase in the strength of the differential-mode interfering signal.

## 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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