Newly developed Compact Isolation Transformers for Signaling Networks

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Abstract: This paper describes the specifications of newly developed compact isolation transformers for signaling networks such as telecommunication installations and information installations. These networks can use isolation transformers to mitigate surges occurring on services. It means that isolation transformers are used to eliminate the affect of noise and common mode voltage. Also the isolation transformers provide lightning protection for these networks. As the specifications of conventional isolation transformers are not sufficient, small-sized isolation transformers were developed. The new isolation transformers offer high isolation withstand voltage (50kV, 1.2/50μs) with low insertion loss (0.5dB) in the transmission frequency band of 500Hz to 30 MHz. The weight is only 0.3kg and the size is only 6×6×5cm.

Key-Words: isolation transformer, isolation withstand voltage, low insertion loss

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1 Introduction

EMC technologies have been introduced in the articles [1]-[13]. One of EMC technologies to be considered is isolation transformers.

This paper describes the specifications of newly developed compact isolation transformers for signaling networks such as telecommunication installations and information installations. These networks can use isolation transformers to mitigate surges occurring on services.

Recommendation ITU-T K.95 gives test methods and preferred values for the isolation transformer surge parameters [14]. Recommendation ITU-T K.126 discusses isolation transformer parameters and how they influence the equipment common-mode surge [15]. IEC 61643-352 covers the application of surge isolation transformers that are used in telecommunication applications [16]. Even these documents provide basic parameters on isolation transformers, product design features and evaluation test results of them were not addressed. Therefore this paper describes product design features and evaluation test results of small-sized isolation transformers developed. These new isolation transformers include three types that are designed for low-speed 64 kHz lines, medium-speed 1.5 MHz and 2 MHz lines, and high-speed 6.3 MHz and 8 MHz lines.

These transformers offer high isolation withstand voltage (50kV,1.2/50μs) with low insertion loss (0.5dB) in the transmission frequency band of 500Hz to 30 MHz.

2 Need for development of small-sized isolation transformers

Isolation transformers have been used mainly in hill-top base stations, where lightning damage is frequent. The comparisons of conventional and newly developed isolation transformers made by Sankosha [17] are listed in Table 1.

Table 1 Comparison of conventional and newly developed isolation transformers

	Conventional	New developed
Insertion loss	1dB (3.4kHz)	0.5dB (500Hz~30MHz)
Withstand voltage	30kV(1.2/50μs)	50kV(1.2/50μs)
Weight	10kg	0.3kg
Size	10×10×10 cm	6×6×5 cm

When isolation transformers are used in hill-top base stations, where there are generally only several cables, there is no problem of space for installing the transformers, each of which weighs 10 kg and is 10×10×10 cm in size. Also, the insertion loss is a large 1 dB. Furthermore, the isolation withstand voltage against lightning surge is a low 30 kV.

On the other hand, within buildings, the isolation transformers should be smaller and lighter and to have lower insertion loss and higher isolation withstand voltage than conventional isolation transformers. It is necessary to develop new isolation transformers that satisfy the specifications described in the next section.

The performance of similar products other than Sankosha is inferior to that of new products.

A dedicated distribution frame was also developed to install the new isolation transformers with necessary function for terminating cables.

3 Specifications of the new isolation transformers

Here, the specifications of the new isolation transformers are presented in detail.

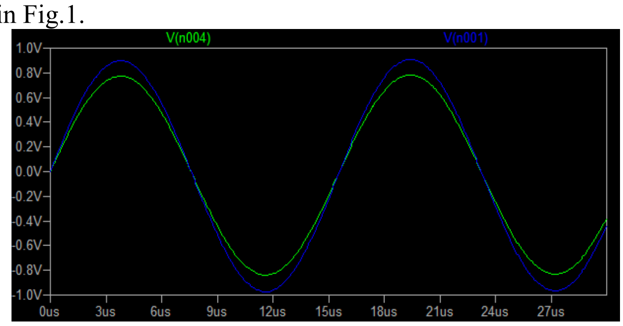
3. 1 Insertion loss

A total of five transmission rates are available for the metallic lines that are used for isolation transformers: 64 kHz, 1.5 MHz and 2 MHz for metal-sheathed balanced pair cable and 6.3 MHz and 8 MHz for coaxial cable.

In order for the insertion loss to satisfy the overall loss allocation for the entire signaling networks at those transmission rates, the insertion loss must be less than 0.5 dB. Because it is difficult to meet this requirement for insertion loss of 0.5 dB over a broad frequency range using one isolation transformer, the frequency band is divided into three parts according to transmission rate as listed in Table 2 [18].

That is to say, there are three types of transformers, one for high-speed transmission at 6.3MHz or 8 MHz over coaxial cable, one for medium-speed transmission at 1.5MHz or 2MHz over balanced pair cable, and one for low-speed transmission at 64kHz over balanced pair cable.

The simulation signals of conventional and new transformer (Low-speed transmission at 64kHz) are shown in Fig.1.



(X 3usec/div, Y 0.2V/div)

Blue line: new, Green line: conventional

Fig.1 Spice simulation signals of conventional transformer and new transformer

Table 2 Insertion loss of the new isolation transformers

	Transmission rate (Hz)	Frequency band (Hz)	Insertion loss(dB)
High-speed	6.3M 8M	100k~30M	0.5
Medium-speed	1.5M 2M	10k~8M	0.5
Low-speed	64k	0.5~400k	0.5

3. 2 Balance (LCL)

The degree of balance is expressed by the Longitudinal Conversion Loss (LCL), which is the ratio for converting the voltage between a two-wire lines and earth (i.e., the common mode voltage) to the voltage between the wires (i.e., the differential voltage).

Table 3 LCL of the new isolation transformers

	Frequency (Hz)	LCL (dB)
Medium-speed	10k	85
Medium-speed	1.5M	50
Medium-speed	2M	45
Low-speed	500	85
Low-speed	64k	60
Low-speed	400k	50

The LCL values for the isolation transformers that are used for medium-speed transmission over balanced pair cable and that of the transformers for use with low-speed lines must be equal to or greater than the characteristics of cables as listed in Table 3 [18].

3.3Characteristic impedance

The characteristic impedance of the isolation transformers must be the same as that of the cables in order to reduce signal reflection. For that reason, a tolerance of -10 to +10 % is allowed in the characteristic impedance specification as listed in Table 4 [18].

Table 4 Characteristic impedance of the new isolation transformers

	Characteristic impedance (Ω)	Tolerance (%)
High-speed	75	-10 ~ +10
Medium-speed	110	-10 ~ +10
Low-speed	110	-10 ~ +10

3. 4 Isolation withstand voltage

In the case of the maximum current flow of 200 kA caused by a direct lightning strike on the building, the LEMP (Lightning Electro-Magnetic Pulse) generates an induced voltage of 50 kV [19]-[21]. Therefore the isolation withstand voltage specification is set at 50 kV.

3. 5 Surge transfer ratio

The surge transfer ratio means that common mode lightning surge voltage is transferred from the primary windings to the secondary windings. It is determined to be 1/50 from the consistency of the insertion loss and the isolation withstand voltage.

4 Product design features of the new isolation transformers

The problems involved in the development of the new isolation transformers were to reduce the insertion loss and to achieve a high isolation withstand voltage while maintaining small-size and light weight.

The insulation has physical paths such as winding insulating material between the two windings. Surface distance should be set so that the maximum expected voltage difference do not cause surface flashover. Solid insulation thickness should be set so that the maximum expected voltage difference does not cause breakdown.

To overcome those problems, the points listed below were implemented so as to achieve the low insertion loss of 0.5 dB for the respective transmission speeds while maintaining a high withstand voltage of 50 kV against lightning surge.

(1) Photographs of the isolation transformers are shown in Fig. 2. The isolation transformer shown in the upper part of the figure is the one that has conventionally been used in hill-top base stations. This conventional isolation transformer has metal case and screw-type terminals.

The isolation transformers shown in the lower part of Fig. 2 are the newly developed ones. From left to right, they are the high-speed, medium-speed, and low-speed transformers. These isolation transformers have plastic cases. The transformer terminals are BNC connectors for the high-speed unit and spring-pressure wire connectors for the medium-speed and low-speed units. The high-speed, medium-speed and low-speed transformers respectively weigh 220 g, 230 g and 310 g, which is 1/30 comparing to that of conventional isolation transformer (10 kg). The size, too, has been reduced, with the largest low-speed isolation transformers being 6×6×5 cm, is 1/5 comparing to that of conventional isolation transformer (10×10×10 cm).

(a) Upper: conventional , (b) Lower : newly developed

Fig.2 External appearance of transformers

(2) To ensure an insertion loss of 0.5 dB or less over a wide range, a Mn-Zn ferrite magnetic core, which has a high magnetic permeability and low high-frequency loss, was used. The core configuration was the E-I shape because of the requirement for high isolation withstand voltage.

(3) To achieve small size and light weight, the conventional metal case for housing was replaced with a plastic case and the conventional screw-type terminals were replaced with BNC connectors in the case of the high-speed transformers and spring-pressure wire connectors in the case of the medium-speed and low-speed transformers.

(4) To ensure a high isolation withstand voltage over a broad frequency range, a thin polyester film was used to insulate the windings and multiple layers were used to reduce the defects in the film. Moreover, a two-liquid urethane resin was used as a filler material and a vacuum was applied to eliminate air bubbles.

(5) Fig.3 shows the structure of the new isolation transformers. To prevent surface flashover between the cable terminals of the transformer and the metal frame of the distribution frame, a plastic threshold plate was placed so as to cover the lower half of the BNC connectors of the high-speed insulating transformers. For the medium-speed and low-speed isolation transformers, spring-pressure terminals were used to prevent surface flashover from the terminals and the metal frame so as to make the surface distance at least 50 mm as shown in Fig.3. In this way, an isolation withstand voltage of 50 kV against lightning surge was achieved.

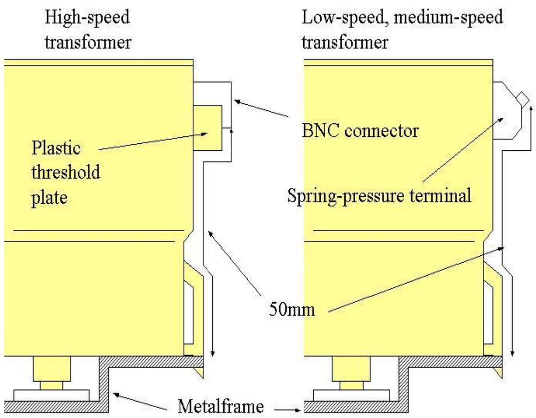


Fig.3 Structure of the new isolation transformers

(6) The new isolation transformers mounted in the distribution frame are shown in Fig. 4. The size of the newly developed distribution frame is 795 (W)×600 (D)×1800 (H) mm. This distribution frame can accommodate 120 medium-speed isolation transformers or 80 high-speed or low-speed isolation transformers. This distribution frame also allows terminating cables.

Fig.4 Distribution frame developed for the new isolation transformers

5 Electrical evaluation test results of the new isolation transformers

In this section, the electrical evaluation test results of the new isolation transformers are described.

5.1 Insertion loss

The insertion loss of the high-speed, medium-speed, and low-speed isolation transformers were measured using the circuit shown in Fig. 5. LM (Level Meter) is a kind of network analyzer to measure the output signal level in dB.

The insertion loss is defined as a ratio of the signal level without the transformer to the signal level with the transformer installed.

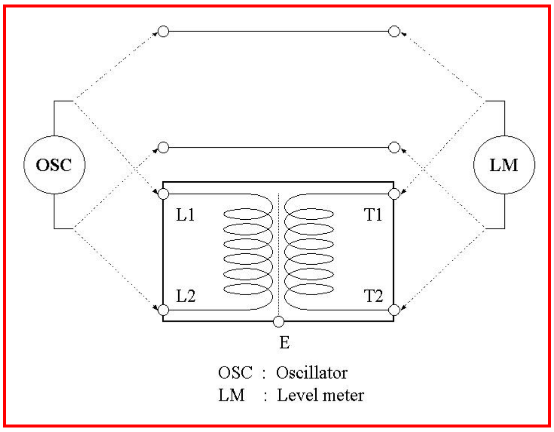


Fig.5 Circuit for measuring insertion loss

The measured frequency characteristics of the high-speed isolation transformers are presented in Fig. 6.

The measured values of the insertion loss of all isolation transformers are listed in Table 5. The required value of 0.5 dB insertion loss was satisfied by all over the entire frequency band.

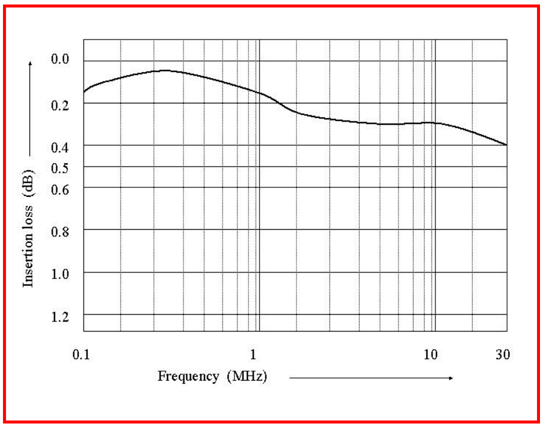


Fig.6 Frequency characteristic of insertion loss for high-speed isolation transformer

Table 5 Measured values of the insertion loss

	Frequency (Hz)	Insertion loss (dB)
High-speed	100k	0.15
High-speed	8M	0.28
High-speed	30M	0.40
Medium-speed	10k	0.28
Medium-speed	2M	0.12
Medium-speed	8M	0.26
Low-speed	500	0.35
Low-speed	64k	0.20
Low-speed	400k	0.44

5.2 Balance (LCL)

The LCL measuring circuit is shown in Fig.7 and the measured values are listed in Table 6.

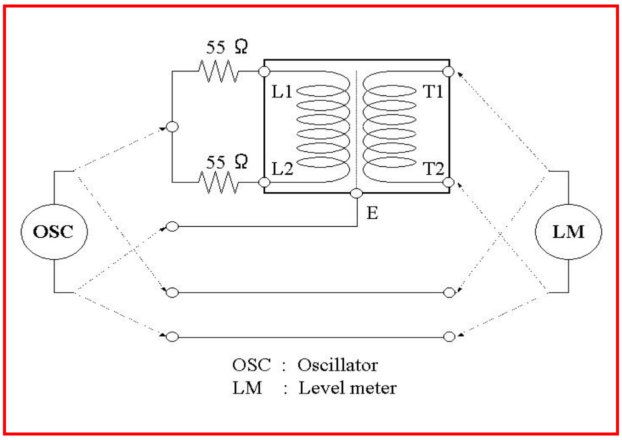


Fig.7 Circuit for measuring LCL

Table 6 Measured values of LCL

	Frequency (Hz)	LCL (dB)
Medium-speed	10k	91
Medium-speed	1.5M	66
Medium-speed	2M	51
Low-speed	500	94
Low-speed	64k	86
Low-speed	400k	73

The required values of LCL were satisfied by all of the transformers over the entire frequency band.

5.3 Characteristic impedance

The circuit for measuring the characteristic impedance is shown in Fig.8.

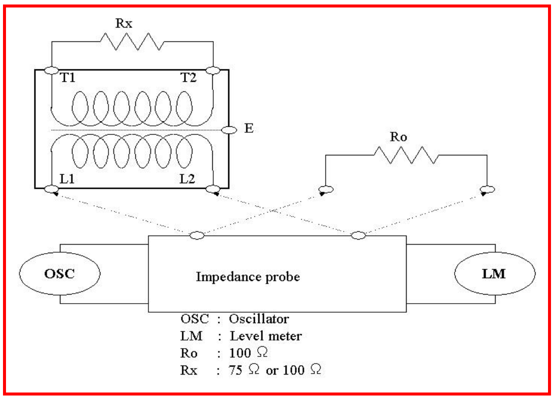


Fig.8 Circuit for measuring characteristic impedance

The measured characteristic impedance values are listed in Table 7. The measured characteristic impedance values of each of the isolation transformers deviated somewhat from the characteristic impedance value of 75Ω for the high-speed isolation transformer and the 110 Ω value for the medium-speed and low-speed isolation transformers, but the deviation in the characteristic impedance values were from -9 to +9 %, within the -10 to +10 % tolerance of the specification.

Table 7 Measured values of the characteristic impedance

	Frequency (Hz)	Characteristic impedance (Ω)
High-speed	100k	71
High-speed	8M	71
High-speed	30M	71
Medium-speed	10k	101
Medium-speed	2M	110
Medium-speed	8M	118
Low-speed	500	109
Low-speed	64k	114
Low-speed	400k	120

5.4 Isolation withstand voltage

The method for measuring the isolation withstand voltage is illustrated in Fig.9.

The voltage across the primary windings and the secondary windings was increased in 0.2 kV steps up to 55 kV (1.2/50μs) and the voltage just prior to failure of the insulation was taken to be the isolation withstand voltage. The measured values of the isolation withstand voltage are listed in Table 8.

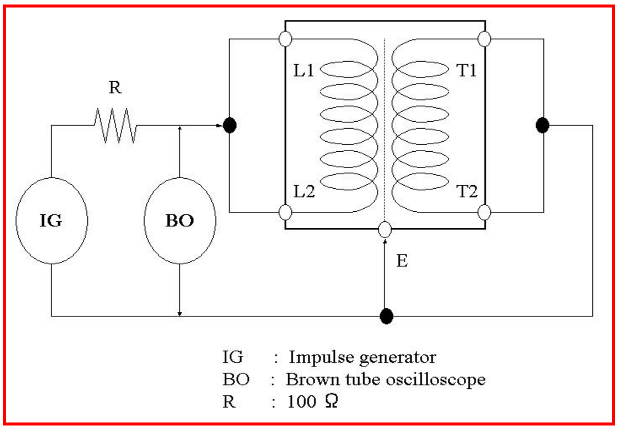


Fig.9 Circuit for measuring isolation withstand voltage

The measured isolation withstand voltage for each of the isolation transformers were in the range of 50.2 to 53.4 kV, exceeding the required value of 50 kV.

Table 8 Measured values of the isolation withstand voltage

	Sample No.	Voltage (kV)
High-speed	1	52.6
High-speed	2	51.8
High-speed	3	53.4
Medium-speed	1	50.2
Medium-speed	2	50.6
Medium-speed	3	50.6
Low-speed	1	51.0
Low-speed	2	51.4
Low-speed	3	51.4

5. 5 Surge transfer ratio

The surge transfer ratio is expressed by the common mode voltage between a two-wire lines and earth. And this surge transfer is caused by capacitive coupling between primary windings and secondary windings. These transformers have a screen between the primary windings and the secondary windings in order to eliminate this capacitive coupling. The surge transfer ratio measuring circuit is shown in Fig.10.

A surge voltage of 10 kV (1.2/50μs) was applied to the primary side and the voltage generated on the secondary side was measured. The surge transfer ratio was obtained from the ratio of this input voltage and output voltage. Example of measured input voltage and output voltage waveforms are shown in Fig. 11.

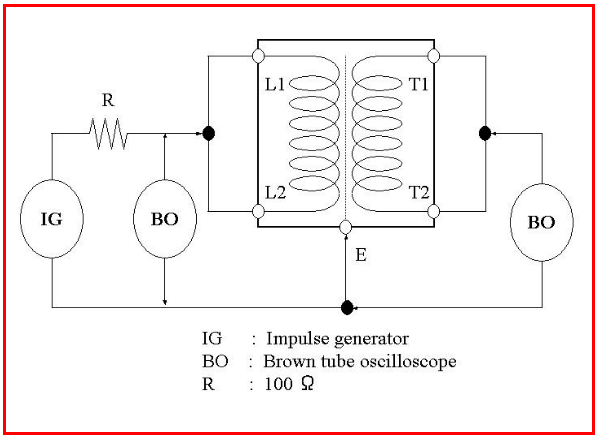


Fig.10 Circuit for measuring surge transfer ratio

For the input voltage of 10 kV (CH1), the output voltage is 194 V (CH2), giving a surge transfer ratio of 1/52.

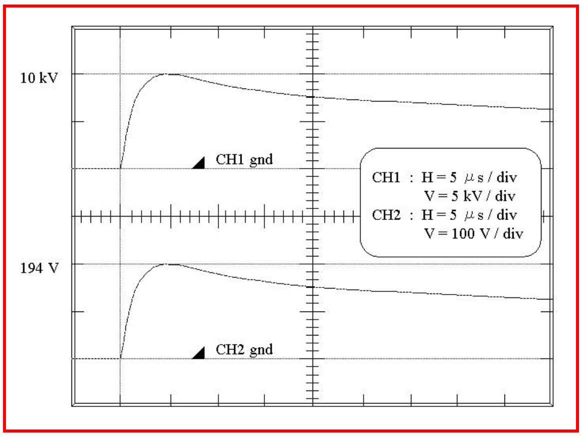


Fig.11 Example of measured input voltage and output voltage waveforms

Table 9 Measured values of the surge transfer ratio

	Sample No.	Ratio
High-speed	1	1/52
High-speed	2	1/54
High-speed	3	1/53
Medium-speed	1	1/63
Medium-speed	2	1/66
Medium-speed	3	1/65
Low-speed	1	1/97
Low-speed	2	1/88
Low-speed	3	1/95

The measured values of the surge transfer ratio are listed in Table 9. The measured surge transfer ratios for the high-speed, medium-speed and low-speed isolation transformers are in the range of 1/52 to 1/97, satisfying the required value of 1/50.

6 Conclusion

We developed small-sized isolation transformers for signaling networks such as telecommunication installations and information installations.

These new isolation transformers include three types that are designed for low-speed 64 kHz lines, medium-speed 1.5 MHz and 2 MHz lines, and high-speed 6.3 MHz and 8 MHz lines. By implementing the design features listed below, we have achieved the high isolation withstand voltage of 50 kV while maintaining insertion loss of 0.5 dB for the respective transmission speeds.

The weight is only 0.3kg and the size is only 6×6×5cm.

(1)To ensure an insertion loss of 0.5 dB or less over a wide range, a Mn-Zn ferrite magnetic core, which has a high magnetic permeability and low high-frequency loss, was used. The core configuration was the E-I shape because of the requirement for high isolation withstanding voltage.

(2)To achieve small size and light weight, the conventional metal case was replaced with a plastic case and the conventional screw-type terminals were replaced with BNC connectors in the case of the high-speed transformers and spring-pressure wire connectors in the case of the medium-speed and low-speed transformers.

(3)To ensure a high isolation withstand voltage while maintaining broadband frequency characteristics, a thin polyester film was used to insulate the windings and multiple layers were used to reduce the defects in the film. Moreover, a two-liquid urethane resin was used as a filler material and a vacuum was applied to eliminate air bubbles.

(4)To prevent surface flashover between the cable terminals of the transformer and the metal frame of the distribution frame, a plastic threshold plate was placed so as to cover the lower half of the BNC connectors of the high-speed isolation transformers. For the medium-speed and low-speed isolation transformers, spring-pressure terminals were used to prevent surface flashover from the terminals and the metal frame so as to make the surface distance at least 50 mm. In this way, an isolation withstand voltage of 50 kV against lightning surge was achieved.

(5) A dedicated distribution frame was also developed to install the new isolation transformers with necessary function for terminating cables. This distribution frame can accommodate 120 medium-speed isolation transformers or 80 high-speed or low-speed isolation transformers.

(6) As a future research, we would like to develop isolation transformers for much more high frequency signaling networks.

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