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PAPER

Design Method of Impedance Stabilization Networks for Measuring Disturbances at Balanced Multiple-Pair Telecommunication Ports

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SUMMARY This paper proposes a design method of impedance stabilization network (ISN) which can measure disturbance at balanced multiple-pair telecommunication ports for both analog and digital signal transmission.The proposed design method of ISN is studied on the basis of the equivalent circuit of ISN and the requirements for ISN. The parameters for designing of ISNs up to 100-wires are studied and determined. An ISN for 4-wire signal ports is constructed on the basis of the proposed design method, and the characteristics of the ISN are experimentally examined. The results show the ISN satisfies the requirements for ISN. Furthermore, the measurement deviation is within 1dB compared with other ISN, and the disturbance measured by the ISN shows a good correlation with that measured by a current probe.

key words: *disturbance, common mode, unbalance, ISN*

1. Introduction

Wide introduction of digital, high-speed and broad band equipment in the field of advanced information systems has resulted in a large increase in electromagnetic noise and the resulting interference among systems. For telecommunications systems, this interference has also aroused an interest in the problems of electromagnetic compatibility (EMC). To restrict electromagnetic noise and to achieve EMC, the International Special Committee on Radio Interference (CISPR) has been investigating the additional requirements for emission from information technology equipment connected to public network or local area networks [1], [2].

The basic frequency and its harmonics of digital signals used in digital processing circuit and switching regulator leak to the telecommunications line and the common mode current appears on the cable. The common mode current generates electromagnetic field around the cable, and the field interferes the radio wave reception. The relation between the field strength and the common mode current has been studied to determine the limits of conducted common mode disturbance [3]-[5]. On the one hand, the telecommunications signal is converted to common mode current due to the unbalance of cable. So, this current may also interfere the radio wave reception [5], [6]. The relation between the common mode level converted due to the unbalance of cable and the signal level has been also studied [6]-[10]. After a long discussion taking account the relations mentioned above, the CISPR has defined limits and measurement methods of conducted common mode disturbance at telecommunication ports [2].

It is well known that an impedance stabilization network (ISN) is used to measure the disturbance at 2-wire telecommunication ports [11]. The CISPR Sub-Committee G (CISPR/SCG) which is in charge of emission and immunity requirements for information technology equipment (ITE) has been studying the measurement methods of disturbance at telecommunication ports [2], and has suggested that the use of appropriate ISNs are needed when measuring the disturbance at various types of telecommunication ports in order to get measurement reproducibility [12]. On the basis of the agreement, various types of ISNs for measuring the disturbance at telecommunication ports have been proposed [2], [13], [14].

Recently developed telecommunications systems use high-speed digital signals, and cables including more than 4-wire (balanced 2-pair) are used to communicate between telecommunications terminals. Therefore, ISNs should be designed taking account the disturbance measurement at both conventional analog signals and digital signals, and furthermore, the disturbance measurement at telecommunication ports using more than 4-wires. An ISN for 2-wire (a balanced pair) telecommunication ports is already available [11]. A type of 4-wire ISN have been proposed in CISPR/SCG [2], but ISNs that can be used for the measurement at more than 4-wire have not been clarified.

In this paper, a design method of ISN for balanced multiple-pair telecommunication ports is described. First, we show a problem relating to measurement error when the disturbance at multiple-pair telecommunication ports is measured by 2-wire ISNs. Next, we show the design method of ISN up to 100-wire and show that the ISN can be used for emission measurement at both analog and digital telecommunication equipment. Finally, in order to confirm the validity of the design method, a 4-wire ISN is developed on the basis of the design method. Then, we show the characteristics of the 4-wire ISN and estimation results on measurement deviation in comparison with disturbance measured by another type of ISN and that measured by a current probe.

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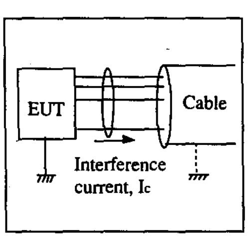
2. Impedance Stabilization Network for Measuring the Disturbance at Telecommunication Ports

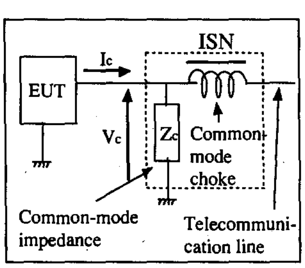
2.1 Construction of Impedance Stabilization Network

An impedance stabilization network (ISN) is a probe which simulates the network seen by the telecommunication ports of the equipment under test (EUT) as shown in Fig. 1(a). The ISN is connected to the telecommunication ports instead of telecommunications cable, and the disturbance voltage or current that appers between the telecommunication ports and the reference metal ground plane is measured. The basic configuration of an ISN is shown in Fig. 1(b). An ISN is constructed by a common mode impedance and a common mode choke. The common mode impedance stabilizes the impedance between the telecommunications cable and the ground to achieve the reproducibility of the measurement. The common mode choke suppresses the disturbance travelling from an associated equipment (AE) of the equipment under test (EUT) in order not to affect the measurement of EUT's disturbance. Here, the AE is the equipment in order to exercise the EUT's normal operation. Thus an ISN is interposed in the telecommunications cable between the EUT and an AE, and defines the common mode impedance seen by the telecommunication ports during the disturbance measurements, and provide sufficient isolation against disturbance from an AE.

However there are various types of telecommunications cables, ISNs for measuring the disturbance at unshielded twisted pair (UTP) cable are taken up a subject for discussion in this paper. Usually the main telecommunication port which uses the UTP cable is a single pair (2-wire) telecommunication ports, but with the advance of such private telecommunications system as local area network (LAN), telecommunications equipment or systems which use multiple-pair telecommunications cable are on the increase. For example, ISDN systems and LAN systems usually use 8-wire telecommunications cable, and PBXs use above 100-wire telecommunications cable. Therefore, it is important to establish the design method of ISNs for measuring the disturbance at multiple-pair telecommunication ports.



(a) Basic concept



(b) Basic configuration of ISN

Fig. 1 Basic concept and configuration of ISN.

2.2 Problems on Disturbance Measurement at Multiple-Pair Telecommunication Ports Using Plural 2-Wire ISNs

When measuring the disturbance at multiple-pair telecommunication ports, it is well concceivable to use plural 2-wire ISNs for the measurement. In order to clarify the problems on this measurement, we show the flow of the disturbance current when measuring the disturbance at 4-wire (2-pair) telecommunication ports using two 2-wire ISNs for the simplicity point of view. The equivalent circuit for measuring disturbance at 4-wire telecommunication ports using two 2-wire ISNs is shown in Fig. 2. In Fig. 2, I_{E1} and I_{E2} are the common mode currents which contribute radio interference. However, as shown in Fig. 2, the current I_{SD} between two balanced pairs also flows through the level meter. Therefore both currents of $I_{E1} + I_{SD}$ or $I_{E2} + I_{SD}$ are measured when measuring the disturbance using two 2-wire ISNs. An example of disturbance voltage measured by two 2-wire ISNs and, measured by a 4-wire ISN are shown in Fig. 3 and Fig. 4, respectively. By comparing Figs. 3 and 4, the measurement using two 2-wire ISNs causes significant measurement errors.

In Figs. 3 and 4, measured datum indicated with circles are the disturbances that apper between the telecommunication ports and the reference metal ground plane, but other measured datum are the disturbances due to the round trip current from A-pair to B-pair. Therefore, measured disturbances shown in Fig. 3 do not stand for the disturbance that defined by the Vc (or Ic) shown in Fig.1(b). Consequently, it is not possible to measure the accurate disturbance at multiple-pair telecommunication ports using plural 2-wire ISNs.

ISNs that have been proposed up to now are limited for use below 4-wire telecommunication ports[2], it is therefore necessary to develop ISNs that can be applied for the disturbance measurment at multiple-pair telecommunication ports.

On the basis of the background mentioned above, we studied the design method of ISNs for measuring disturbances at multiple-pair telecommunication ports.

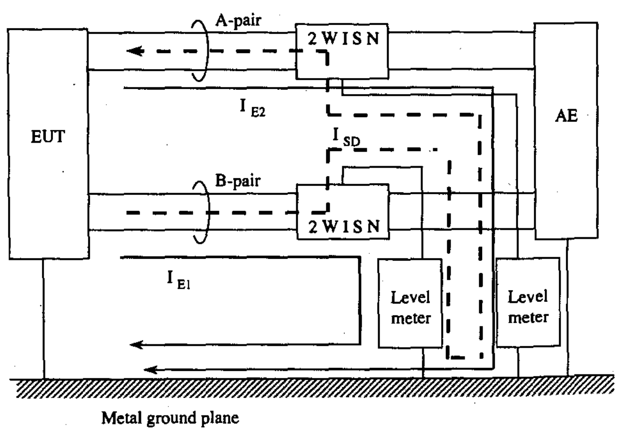


Fig. 2 Equivalent circuit when two 2W ISN are used to measure disturbance voltage at telecommunication ports with 4W cable.

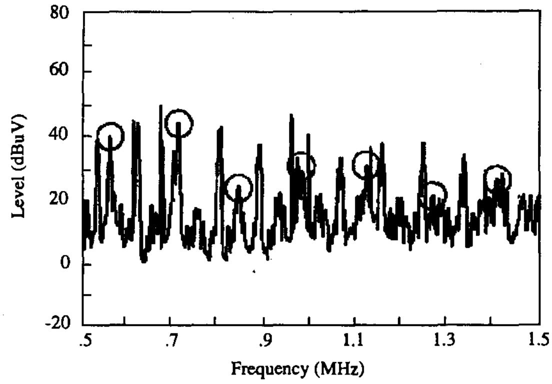


Fig. 3 Disturbance voltage measured by two 2W ISN.

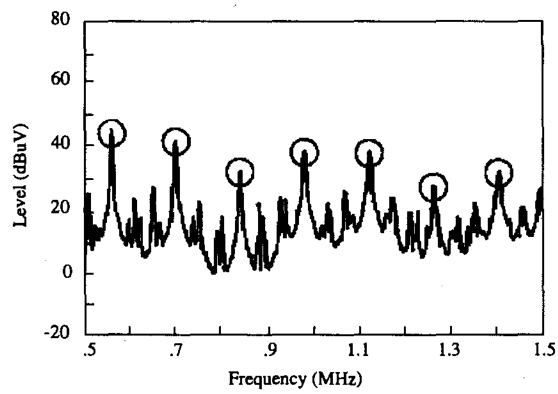


Fig. 4 Disturbance voltage measured by newly developed 4W ISN.

3. Design Method of ISN for Multiple Wire Telecommunication Ports

3.1 Configuration of ISN

The basic concept and configuration in Figs. 1(a) and 1(b) lead the configuration of the proposed ISN as shown in Fig. 5. An impedance Za terminates between each wire and ground, and the common mode chokes constructed on one core with winding all wires is inserted between the EUT and telecommunications line.

The ISN shown in Fig. 5 satisfies the basic concept and configuration of ISN, and is able to use for the disturbance measurement at multiple-pair telecommunication ports if the ISN is well designed to meet the requirements for measuring the disturbance at telecommunication ports. To measure the disturbance level at telecommunication ports from 150 kHz to 30 MHz, CISPR/SCG proposes the basic requirements for ISN shown in Table 1 [2]. It is necessary for ISNs to satisfy the requirements shown in Table 1. In the following sub-clause we show a design method of ISN that is applicable for disturbance measurement at multiple-pair telecommunication ports.

3.2 Equivalent Circuit of ISN

The equivalent circuit of an ISN is important to determine the circuit parameters of the ISN and to study the influence of each device to the characteristics of the ISN. Tow types of currents are considered in the ISN. One is common mode current and the other is differential mode current which means the telecommunication signal between wires. The ISN shown in Fig. 5 uses the common mode choke which has different characteristics for the common mode current and the differential mode current. It is therefore convenient to use different equivalent circuit for each current.

The equivalent circuit of the ISN for common mode current is obtained from the configuration in Fig. 5. The circuit is illustrated in Fig. 6. The associate equipment (AE) shown in Fig. 6 represents the equipment to exercise the EUT such as modem tester and network simulator. The EUT and the AE have voltage sources whose internal impedance are

Table 1 Requirements for ISNs proposed by CISPR.

Item	Requirements for ISNs
Common mode impedance	- Amplitude: 150 Ω ± 20 Ω (0.15 - 30 MHz) - Phase angle: 0 deg. ± 20 deg. (0.15 - 30 MHz)
Isolation	- The ISN shall provide sufficient isolation against disturbance from associated equipment (AE) or load connected to the telecommunication ports under test - The attenuation of The ISN, for Common mode current or voltage disturbance originating from the AE, shall be such that the measured level of these disturbances at the measuring receiver input shall be at least10 dB below the relevant disturbance limit
Longitudinal impedance (LCL)	- Specific system unbalance with reference to The ground shall be satisfied in the presence of the ISN - Common mode component of The wanted signal due to insufficient LCL of the ISN shall not influence the measurement - The LCL shall be: ●150 kHz to 1.5 MHz: 80 dB± 3 dB ●1.5 MHz to 30 MHz: (80 dB to 55 dB) ± 3 dB, decreasing linearly with the logarithm of the frequency
Insertion loss	- The attenuation distortion or other deterioration of The signal quality in the wanted signal frequency band caused by the presence of the ISN shall not significantly affect the normal operation of the EUT
Voltage division factor	- The accuracy of the voltage division factor shall be within ± 1.0 dB

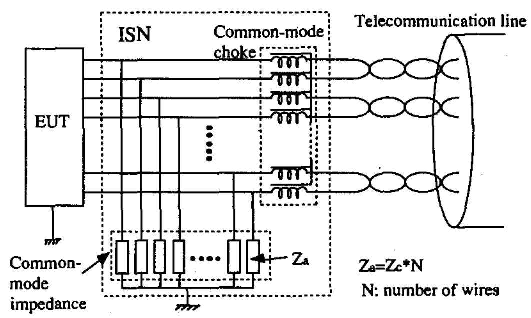


Fig. 5 Configuration of proposed ISN.

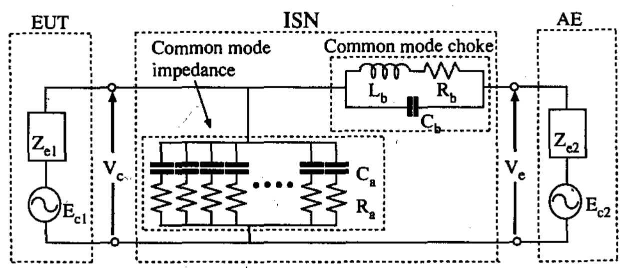


Fig. 6 Equivalent circuit of ISN for common mode current.

Ze_1 and Ze_2, respectively. Here, Ec_1 and Ec_2 represent interference sources in EUT and AE, respectively. The terminating impedance Za shown in Fig. 5 is represented by the series connection with a capacitance Ca and a resistance Ra, and is given by

$$Za = Ra + 1/(j\omega Ca), \quad (1)$$

where Ca blocks the DC current on the telecommunications line and Ra determines the common mode impedance. The common mode choke is usually represented by the parallel resonance circuit as shown in Fig. 6 [14].

The equivalent circuit for differential mode current is illustrated as shown in Fig. 7. Since the interaction between pairs is sufficiently small, the circuit parameters are determined from the equivalent circuit of a balanced pair. In the circuit shown in Fig. 7, Z_0 is the characteristic impedance of the telecommunications line. The input impedances of both EUT and AE are usually the same value. Es is telecommunications signal source. The same characteristics is obtained from the symmetry of the equivalent circuit when Es places not only in the EUT but also in the AE.

3.3 Determination of Circuit Parameter

Circuit parameters of ISN shown in Figs. 5, 6, and 7 are Ra, Ca and the impedance of common mode choke Zd, where Zd is represented by

$$Zd = (Rb + j\omega Lb)/(1 - \omega^2 LbCb + j\omega CbRb) \quad (2)$$

Ra is determined from the requirement for the absolute value of the specified common mode impedance Z_{SC}, and is given by

$$Ra = |Z_{SC}| * N \quad (3)$$

where N is number of wires and $|Z_{SC}|$ is 150 Ω as shown in Table 1.

The value of Ca is determined from the requirements for the common mode impedance and the insertion loss of differential mode current. The insertion loss Fd is calculated using the circuit shown in Fig. 7, and is given by

$$Fd = (E_s/2)/Vd2$$
$$= 1 + Z_0/(4Za). \quad (4)$$

The calculated common mode impedance and insertion loss for differential mode current is shown in Fig. 8. In this figure, the left vertical axis represents the deviation of the common mode impedance from the specified value, and the right vertical axis represents the magnitude of the insertion loss. The dotted line represents the allowable deviation of the common mode impedance shown in Table 1 and the design object of the insertion loss. Figure 8(a) represents the relation between Ca value and the absolute value of the common mode impedance, and Fig. 8(b) represents the relation between Ca and the phase deviation. The relations between Ca and the insertion loss are also represented in this figure. The characteristic impedance of 600 Ω is used because it is severer condition. The maximum deviation of the common mode impedance in frequency range of 0.15-30 MHz and the maximum insertion loss in frequency range of 0.3-10 kHz are represented in these figures for each Ca value.

When the Ca value decreases, the impedance of Ca increases. So, both |Zc| and phase angle(Zc) separate away from the specified value. On the other hand, the insertion loss decreases because the impedance inserted between balanced wires is higher with decrease of the value of Ca. When the Ca value increases, the deviation of both |Zc| and phase angle(Zc) decrease, but the insertion loss increases. This means the optimum Ca value is existing. Ca of 10-50 nF is obtained to satisfy both the requirement of common mode

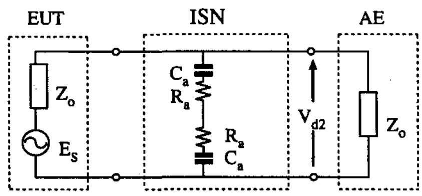
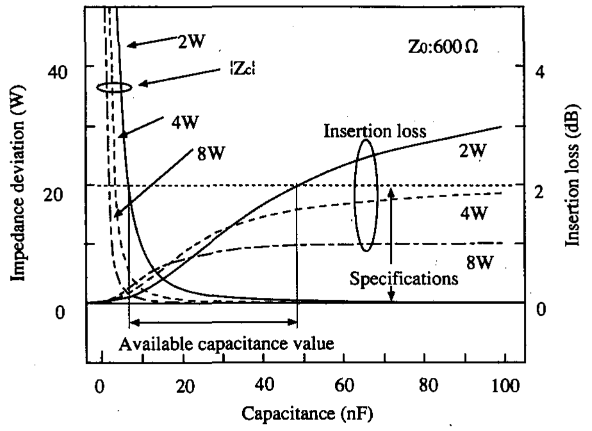
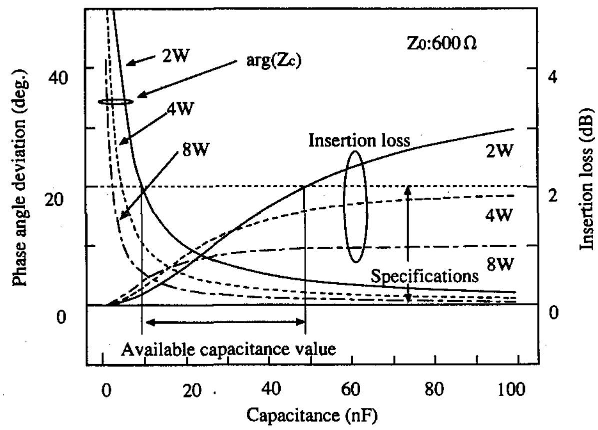


Fig. 7 Equivalent circuit of ISN for differential mode current.



(a) Absolute value of common-mode impedance vs. insertion loss



(b) Phase angle of common-mode impedance vs. insertion loss

Fig. 8 Relation between capacitance (Ca) and common mode impedance, and relation between insertion loss and common mode impedance.

impedance and the design object of insertion loss for 2-wire balanced line, and Ca of about 20 nF is obtained for optimum value. These figure shows that the upper limit of the Ca value when number of wires is more than 4-wire.

The characteristics of a common mode choke influence to the common mode impedance and the isolation of the disturbance travelling from the AE. The common mode impedance Zc including the common mode choke is calculated using the equivalent circuit shown in Fig. 6, and is given by

$$Zc = (Za/N)(Zd+Ze_2)/(Za/N+Zd+Ze_2) \quad (5)$$

The isolation Fc is defined by the transmission loss from the AE side to the EUT side in the circuit shown in Fig. 6. Then Fc is given by

$$\begin{aligned} Fc &= Ve/Vc \\ &= 1+Zd/Ze_1+Zd/Za, \end{aligned} \quad (6)$$

where we assumed the following conditions;

$$Ze = Ze_1 = Ze_2, \quad Ec_1 \text{ is } 0 \quad (7)$$

Here, if Ze_2 is 0, the influence of the common mode impedance Zc is maximum. The deviation and isolation are calculated using Eqs. (5) and (6) in the condition of Ze_2 is 0. The result is shown in Fig. 9. Ca of 20 nF is used as the optimum value and Ze_1 of 50 Ω is used as the isolation measurement condition. The maximum deviation for common mode impedance and the minimum isolation is calculated in frequency range of 0.15-30 MHz. The horizontal axis of Fig. 9 is |Zd|. Ld and Cd values in Fig. 6 is calculated by Eqs. (8) and (9).

$$Ld = |Zd|/(2\pi f_1) \quad (8)$$

$$Cd = 1/\{(2\pi f_2)|Zd|\} \quad (9)$$

where f_1 is the minimum frequency (0.15 MHz) and f_2 is the maximum frequency (30 MHz) in this calculation. Rd of 1 Ω is used as typical value. When Rd is around this value, the influence to the characteristics of the ISN can be neglected.

As sown in Fig. 9, the influence to the common mode impedance can be neglected when |Zd| is more than 1 kΩ, and the isolation is more than 40 dB when |Zd| is more than 3 kΩ. This means that the |Zd| can be determined by the design object of the isolation.

3.4 Longitudinal Conversion Loss

It is known that telecommunications signal also generates the common mode current by the unbalance of the telecommunication cable [6]-[10]. Since the common mode current converted by the unbalance of the telecommunication cable creates the measurement error when measuring the disturbance of EUT, the unbalance of ISN should be maintained in the sufficient low value. The unbalance of the telecommunication cable is defined by the longitudinal conversion loss (LCL) [15] and is given by the following equation [9].

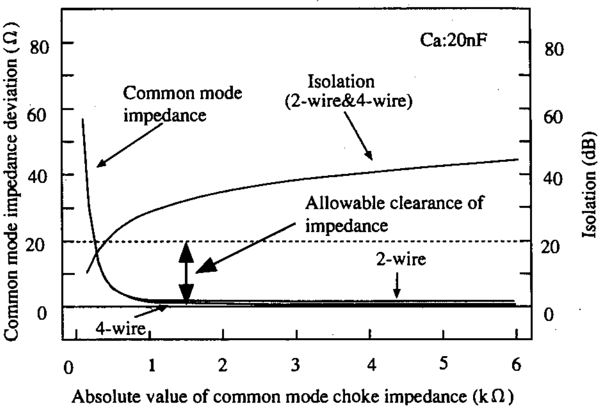


Fig. 9 Relation between common mode impedance and impedance of common mod choke.

$$LCL = \{(Z_1-Z_2)^2+2Zk(2Zk+4ZL)\}/\,2Zk(Z_1-Z_2) \quad (10)$$

here

$$Z_1-Z_2 = 2Z_0\Delta Za/(Z_0+2Za), \quad (11)$$

$$Zk = 2Z_0Za/(Z_0+2Za), \quad (12)$$

$$ZL = Za_2/(Z_0+2Za), \quad (13)$$

where ΔZa is deviation of each Za from these mean value and is defined by

$$2\Delta Za = (Za_1-Za_2)/(Za_1+Za_2), \quad (14)$$

where Za_1 and Za_2 are each Za value of the connected balanced pair.

Substituting Eqs. (11), (12) and (15) to Eq. (10), we get

$$LCL = (\Delta Za/Za)/2 + 2(Za/\Delta Za)\{1 + (Za/Z_0)\} \quad (15)$$

Usually, $(Za/\Delta Za) \gg 1$ and, $(\Delta Za/Za)/2 \ll 2(Za/\Delta Za)\{1 + (Za/Z_0)\}$, then

$$LCL \fallingdotseq 2(Za/\Delta Za)\{1 + (Za/Z_0)\} \quad (16)$$

Equation (16) means that the lower the value of Za or the higher the value of Z_0, the severer (lower) the calculated LCL of the ISN.

The calculation example is shown in Fig. 10. Ca of 20 nF is used as optimum value, Ra of 300 Ω is used as severer condition, and Z_0 of 100 Ω is used as typical value. Horizontal axis in Fig. 10 shows Ra and Ca value deviation represented by Eq.(14). This figure shows that the influence of Ca deviation is smaller than the influence of the Ra. LCL is more than 60 dB when deviation of Ra is up to 0.5% and that of Ca is up to 5%.

3.5 Design of ISN for Multiple-Pair

Most of telecommunications cable uses more than 4 twisted pair. It is therefore necessary to develop ISNs used more than 8-wire telecommunication cable. It is not convenient if fifty types of ISNs are needed to measure disturbance at telecommunication ports from 2-wire to 100-wire. However, the com-

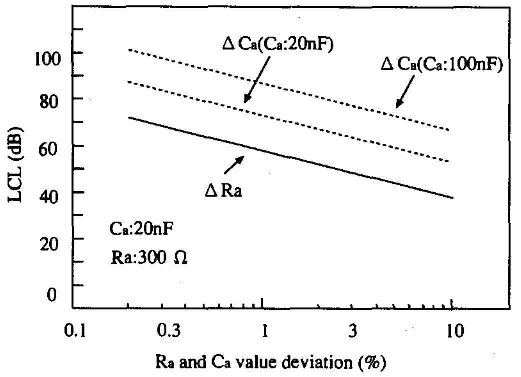


Fig. 10 Calculated result of longitudinal conversion loss.

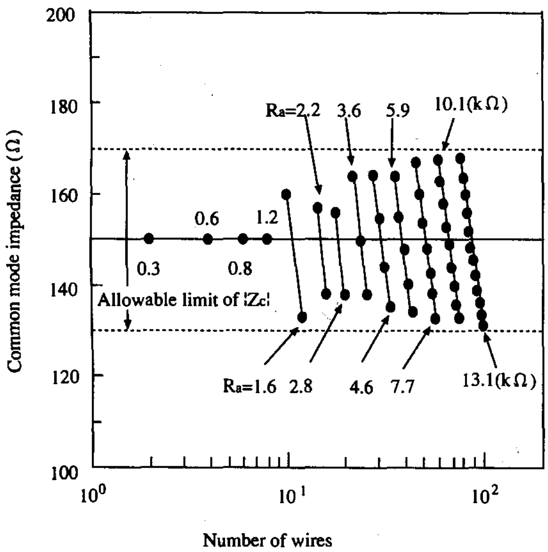


Fig. 11 Calculated results of common mode impedance.

mon mode impedance have a allowable clearance as shown in Table 1. Therefore there is a possibility to measure the disturbance at telecommunication ports for some wires by using only one ISN. In order to clarify the possibility, the common mode impedance of certain number of ISNs are calculated using Eq.(2). Figure 11 shows the calculated common mode impedance. The value shown in this graph represents Ra value, and the vertical and the horizontal axises are common mode impedance and number of wires, respectively. The results show that the disturbance measurement at telecommunication ports from 2-wire to 100-wire can be covered by thirteen ISNs.

Measurement example of the common mode impedance is shown in Fig. 12. An ISN using Ra of 5.9 kΩ was constructed and the common mode impedance was measured. Figure 12 shows that the measured common mode impedance satisfies the requirements for common mode impedance in the case of 38-wire to 42-wire in the frequency range of 0.15-20 MHz. This means that ISNs for measuring the disturbance at multiple-pair can be constructed though the improvement of characteristics relating to common mode impedance in the frequency range of 20-30 MHz is needed.

Calculated parameters and characteristics of ISNs from

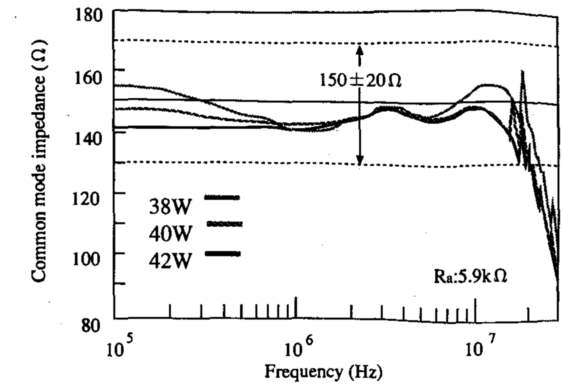


Fig. 12 Measurement example of common mode impedance of multiple-pair ISN.

Table 2 Calculated parameters for ISNs.

Item	Parameters: Number of wire	Ra(kΩ)	Ca(nF)	Characteristics
Common mode impedance	2W	0.3	20	|Zc|: 150 ±20Ω; arg(Zc): ±9 degree
	4W	0.6		
	6W	0.8		
	8W	1.2		
	10-12W	1.6		
	14-16W	2.2		
Insertion loss	18-20W	2.8		600 Ω: <0.9dB (0.3-10 kHz); 100 Ω: <0.8 dB
	22-26W	3.6		
	28-34W	4.6		
	36-44W	5.9		
	46-58W	7.7		
	60-76W	10.1		
	78-100W	13.1		
Isolation	|Zd|: > 3 kΩ	Cd: < 1.7 pF; Ld: > 3.2 mH; Rd: <1 Ω		> 37 dB
LCL	ΔRa : < 0.5%	ΔCa: < 5%		> 59dB

2-wire to 100-wire are summarized in Table 2. This table shows that ISNs satisfying the requirements can be constructed by the design method proposed in this paper.

4. Characteristics of ISN

To confirm the validity of the design method shown in clause 2, a 4-wire ISN was designed and its characteristics were measured. The configuration of newly developed 4-wire ISN is shown in Fig. 13. To stabilize the common mode impedance between all wires and the ground, impedance Ra terminates each wire to the ground through Rb. Rb and Rf form the circuit to measure disturbance voltage at telecommunication ports. The relation between the disturbance voltage and measured value is approximately given by Fa = (Ra/N)/Rb. Here, Fa stands for the voltage division factor shown in Table 1. It is therefore unnecessary to use a current probe for measuring the disturbance level.

The circuit parameters are obtained on the basis of the design method described in clause 3, and each value is also shown in Fig.13. In Fig.13, Ca of 33 nF is used taking account the characteristics that the influence to the common mode impedance and the LCL becomes smaller when the larger value of Ca is selected on the basis of the results shown in Figs. 8 and 10. The disturbance level is obtained by measuring the voltage at the end of Rb, where Rb of 6 Ω is selected to be much lower than the impedance between the wires and the ground. Rf of 44 Ω is used to match the impedance to the input impedance of the level meter.

4.1 Characteristics of ISN

To confirm the validity of the design method, the characteristics of the ISN were measured. Measurement results are summarized in Table 3. The common mode impedance is measured by impedance meter, the common mode noise isolation is measured by the circuit shown in Fig. 7, the LCL is measured by the method recommended by ITU-T [15], the insertion loss for differential mode signal is measured by the circuit shown in Fig. 8. The conversion factor is the difference between the voltage appearing across the 150 Ω common mode impedance and the resulting voltage appearing across a 50 Ω measurement receiver input attached to the measuring port of the ISN. This factor is measured by the high impedance probe and the network analyzer.

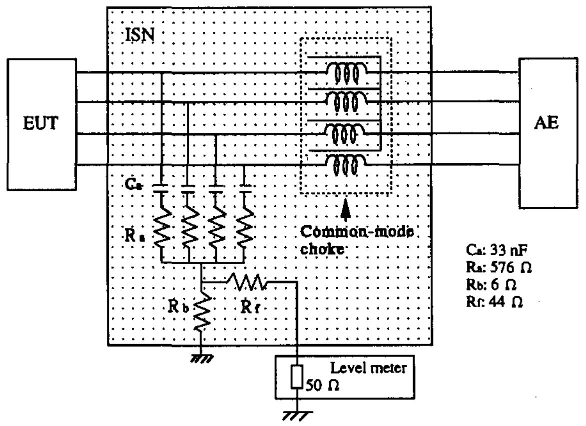


Fig. 13 Configuration of four-wire ISN.

Table 3 Characteristics of 4-wire ISN.

Item	Characteristics
Common-mode impedance	Amplitude: 150 (+ 0 ∼ − 8) Ω (0.15 − 30 MHz) Phase angle: 0 (+ 0 ∼ − 7) deg (0.15 −30 MHz)
Isolation	> 44 dB (0.15 - 30 MHz)
Longitudinal conversion loss (LCL)	> 80 dB (0.15 MHz) > 80 dB (1.5 MHz) > 54 dB (30 MHz)
Insertion loss for signal	600 Ω system: < 2 dB (300 Hz −10 kHz) 100 Ω system: < 2 dB (100 Hz −10 MHz)
Voltage division factor	34 (+ 1 ∼ 0) dB (0.15 − 30 MHz)

Table 3 shows that the newly developed 4-wire ISN almost meets the requirements for ISNs and it has almost the same performance as that of available 2-wire ISN [11]. In particular, the insertion loss of less than 2 dB is achieved for both telecommunications systems whose characteristic impedances are 600 Ω and 100 Ω. This means that the ISN can be used to measure the disturbance at both analog and digital telecommunication ports.

4.2 Usability of ISN

To confirm the usability of the ISN, the disturbances were measured by two types of 4-wire ISNs and the deviation of the measured disturbance was estimated. The conducted emission measurement layout at telecommunication ports for table top equipment is illustrated in Fig. 14 [12]. In CISPR/SCG, when measuring the disturbance level at telecommunication ports, the use of an ISN or a current probe in combination with an ISN is agreed in order to get measurement reproducibility. Then the disturbances were also measured by a current probe in combination with the ISN and the ISN alone, and those results were compared.

4.2.1 Measurement Deviation between Two Types of ISNs

In order to confirm the usability of the newly developed ISN, the disturbance voltages were measured by two types of 4-wire ISNs and the measurement deviation was estimated. One is the ISN proposed by Mr. Pasmooij [2] and the other is the ISN shown in Fig. 13. The test setup is shown in Fig. 14. Three types of equipment with the ISDN basic access interface ports are employed for the EUT and an ISDN simulator is connected to the AE port of the ISN in order to get EUT's normal operation. An artificial mains network (AMN) is inserted in the AC mains line to suppress the common mode disturbances traveling from AC mains. The measurement were repeated five times to estimate the error caused by the resetting of the test setup and the difference of test site. Figure 15 shows the deviation of the measured disturbances between two types of 4-wire ISNs for some stable disturbances. The deviations shown in Fig. 15 are within 1 dB. This means that

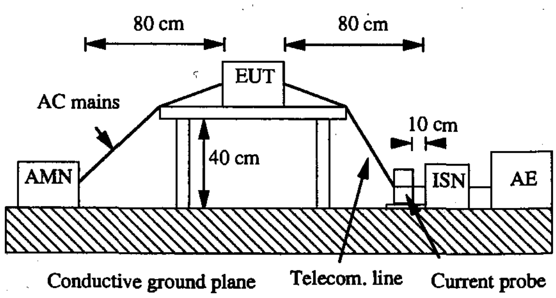


Fig. 14 Layout for measuring disturbances at telecommunication ports.

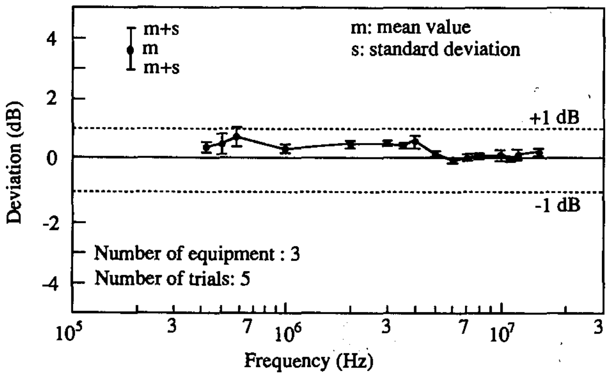


Fig. 15 Measurement deviation between two types of four-wire ISN.

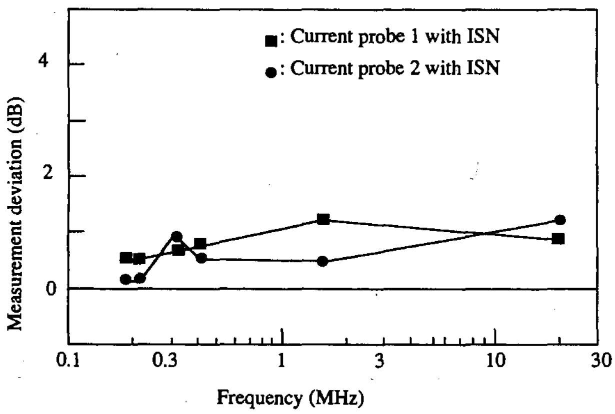


Fig. 16 Deviation in measurement results using current probes with ISN and using ISN alone.

the circuit configuration of the ISN does not influence to the measurement results.

4.2.2 Comparison with the Measurement Using Current Probe

It is convenient to remove a current probe when measuring the disturbance at telecommunication ports from the measurement simplicity point of view. The disturbance level at 4-wire telecommunication ports was measured by a current probe in combination with the ISN and by the ISN alone, and those results were compared. The test setup is the same that shown in Fig. 14.

A digital telephone with ISDN basic access interface port is also employed for the EUT. A current probe is inserted in the telecommunications line at a distance 10 cm from the ISN.

Two types of current probe are used in the measurement. One is R&S ESH2-Z1 and the other is EATON 93686. The measured value by the current probe is converted to voltage value by adding 44 dB [=20log150 (Ω)], and the measured value is compared with that measured by the ISN alone. The result is shown in Fig. 16.

From Fig. 16, the measurement deviation is less than 1.5 dB. This means that the newly developed ISN designed on the basis of the proposed design method can measure the disturbances at 4-wire telecommunication signal ports without a current probe.

5. Conclusion

A new ISN is developed on the basis of the disturbance induction mechanisms. This ISN can measure disturbance voltage at both digital and the analog telecommunication ports of equipment, and thirteen ISNs can cover from 2-wire to 100-wire telecommunication ports. A design method of the ISNs is developed, and the method for determining parameters of ISN is represented on the basis of the equivalent circuit of ISN and the requirements for ISN. The result indicates that the ISNs from 2-wire to 100-wire almost satisfy the requirements for ISN specified by CISPR.

A 4-wire ISN was constructed on the basis of the design method and the performance of the ISN is measured and estimated. As the results, the performance of the ISN almost meets the requirements for ISN specified by CISPR/SCG, and also satisfies the requirements for differential mode signal transmission conditions on both analog and digital telecommunications. The experimental results show that the disturbance level measured by the ISN is almost the same that measured by another type of ISN. Furthermore the ISN can measure the disturbances without a current probe.

ISNs which do not influence the measurement results even if the transmission signal frequency is very high are needed to develop in near future.

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