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Novel Common Mode Filters for Ultra-High Speed Transmissions Exceeding 10 Gbit/s

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Abstract

A common-mode filter (CDLD-Type) for transmission speeds exceeding 10Gbps is realized using a new principle based on the application of Delay Line technologies. With a common-mode elimination circuit constituted within the Delay Line, the filter absorbs and removes the common-mode noise which causes EMI, and improves the eye pattern of the differential signal.

Keyword

Common-mode, Common-mode filter, Noise Absorption, 10Gbit/s, Delay Line

I. Introduction

A differential signaling system is generally used in high speed serial transmission applications. It is capable of ensuring smaller amplitudes for higher transmission speeds and removing external noise by simultaneously transmitting and receiving in-phase and opposite-phase differential voltages to each of two lines which are formed as a pair.

However, as common-mode noise has an in-phase signal (common-mode signal), noise is generated by a slight asymmetry of the differential lines or a slight phase deviation (namely the skew) in the IC [1]. Such noise is propagated through the differential lines and is easily radiated out.

Therefore, in a high-speed serial transmission using differential lines, a method to counteract this common-mode noise is required. A common-mode choke coil is frequently used for removing the common-mode noise.

However, a common-mode choke coil is not available for ultra-high speed transmissions exceeding 10Gbit/s (10Gbps) due to the increase of magnetic loss and the decrease of permeability in a magnetic core.

To solve these problems, development of a common-mode filter which does not utilize a magnetic core has been reported. [2] [3].

We also propose a common-mode filter, the CDLD-Type, which also does not utilize a magnetic core. It has the capability to absorb common-mode noise by a different principle than the above and will operate for transmission speeds exceeding 10Gbps [4].

This paper explains the principle of the CDLD-type and reports the evaluation results of a trial production sample.

II. Characteristics

The CDLD-Type is a common-mode filter based on new principles which operate differently from any existing common-mode choke coil. It is a 2.0mm × 1.2mm footprint, LTCC (Low Temperature Co-fired Ceramic) product, which does not utilize a magnetic core and is therefore not influenced by magnetic loss. Good transmission characteristics of the differential signal are achieved for high-speed serial differential signals of 4G ~ 16Gbps. It is suitable for EMI prevention and the eye-pattern improvement in high-speed interfaces.

Fig. 1 shows an equivalent circuit of the CDLD-Type. Circuit elements displayed as Cb, Lo/2 and Co constitute a Delay Line circuit. Resisters and inductors which are inserted in the central line constitute a common-mode noise absorption circuit.

Because the differential signal does not flow through the noise absorption circuit which is inserted at a zero potential balance point, propagation of the differential signal is managed only by the design value of a Delay Line. In addition, common-mode noise will flow into a noise absorption circuit to return to GND and is absorbed and removed at that point.

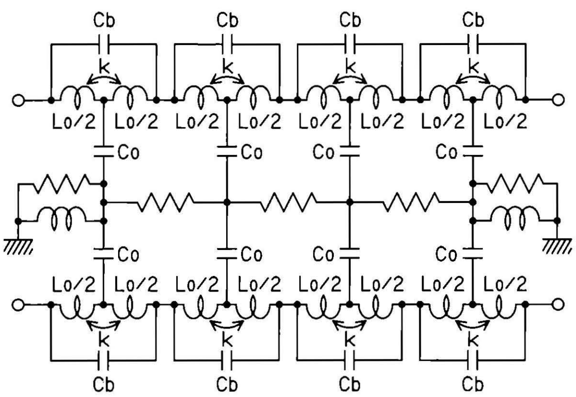


Fig.1 Equivalent Circuit of CDLD-Type

A Delay Line will cause the propagation speed of the common-mode noise to slow, and remain within the noise absorption circuit. Absorption of the common-mode noise is carried out effectively.

Fig.2 shows frequency characteristics of the CDLD15R designed for 10Gbps operation. It consists of three characteristics: transmission for a differential signal (Sdd21), transmission for common-mode noise (Scc21), and Group Delay for a differential signal (GD21).

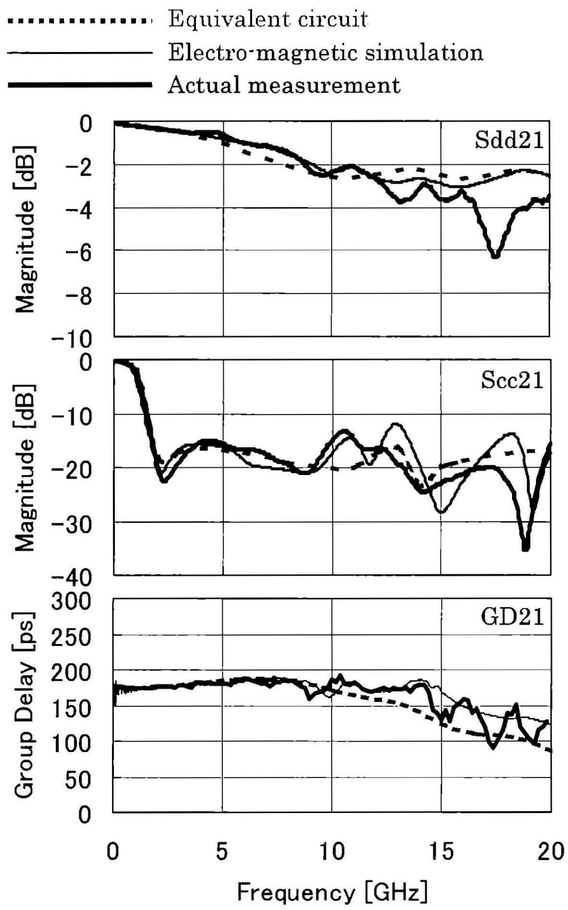


Fig.2 Frequency Characteristics of CDLD15R

Each graph has three curves drawn by a circuit simulation of the equivalent circuit in Fig.1, by the electro-magnetic simulation of the actual structure, and by measuring the actual sample using the equipment shown below.

These curves show that the equivalent circuit of Fig.1 is acceptable as a simulation model of an actual CDLD15R because of good coincidence between simulation results and the measured results. It also shows that the CDLD15R will be acceptable as a common-mode filter for 10Gbps operation because of its wide differential pass-band and sufficient common-mode attenuation.

III. Measuring Equipment

Measuring equipment utilized for frequency characteristics are shown in Fig. 3. These consist of an N5230A 20GHz-4Port Vector Network Analyzer (Agilent Technologies Inc.) and an inspection fixture with a frequency range of 14GHz or more.

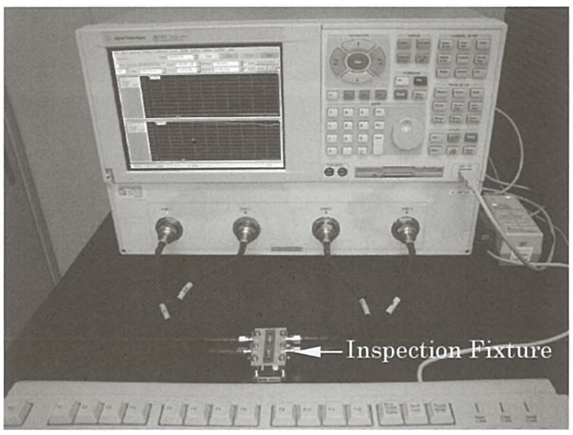


Fig.3 Measuring Equipment for Frequency Characteristics

Fig. 4 shows the measuring instruments for PRBS (Pseudo Random Bit Sequence) response. These consist of an 81250A Differential PRBS signal Generator (Agilent Technologies Inc.) and a DSA91304A 13GHz band-width Oscilloscope (Agilent Technologies Inc.)

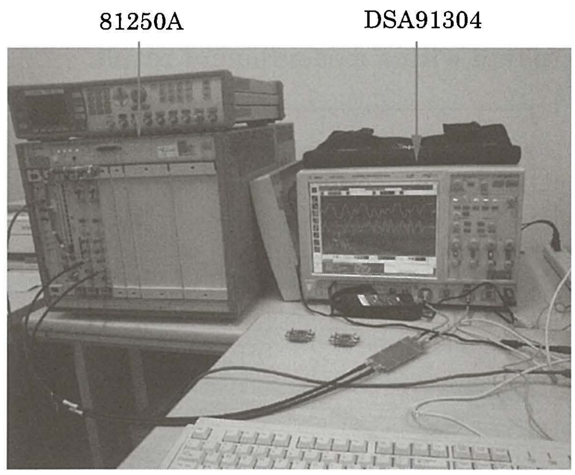


Fig.4 Measuring Instruments for PRBS Response

IV. Common-mode Noise Rejection

The common-mode noise rejection capability of the CDLD15R was measured with the equipment shown in Fig. 4. The equivalent circuit is shown in Fig.5.

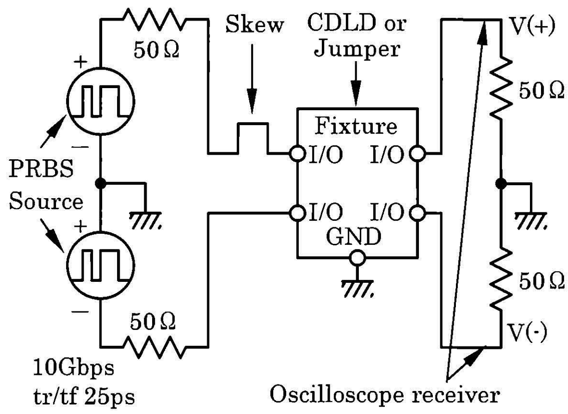


Fig.5 Equivalent Circuit for Measurement of PRBS Response

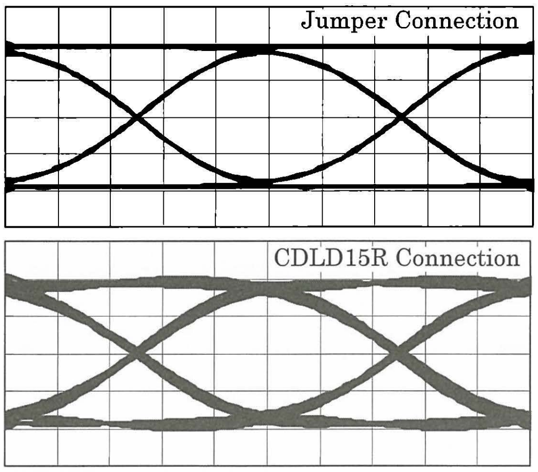
The signal source is a 10Gbps PRBS (Pseudo-Random Bit Sequence) with 25ps rise/fall time. "Fixture" indicates either a CDLD15R connection or a jumper which has a through function.

To confirm the validity of a measurement result, the circuit in Fig. 5 is analyzed with a circuit simulator, and compared with a measurement result.

Fig.6 shows a differential output signal eye-pattern for the CDLD15R or a jumper connection by circuit simulation.

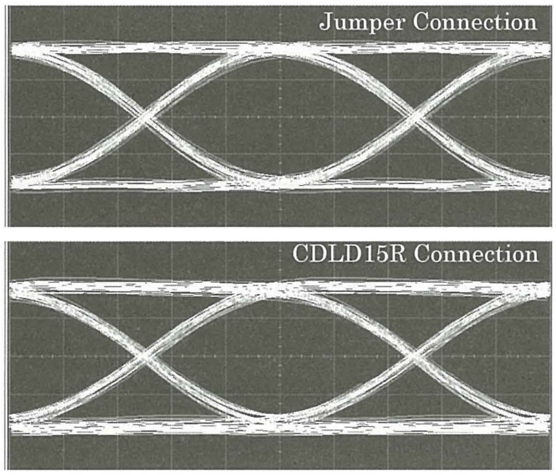
Fig.7 shows waveforms and spectrums of the output common-mode noise corresponding to the above conditions.

Fig. 8 and Fig. 9 show the actual measurement results corresponding to Fig. 6 and Fig. 7, respectively.



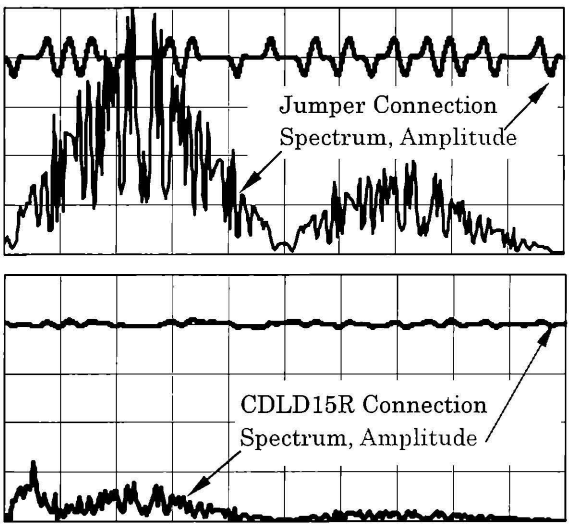
20ps/div(H), 500mV/div(V)

Fig.6 Eye-Pattern by Simulation



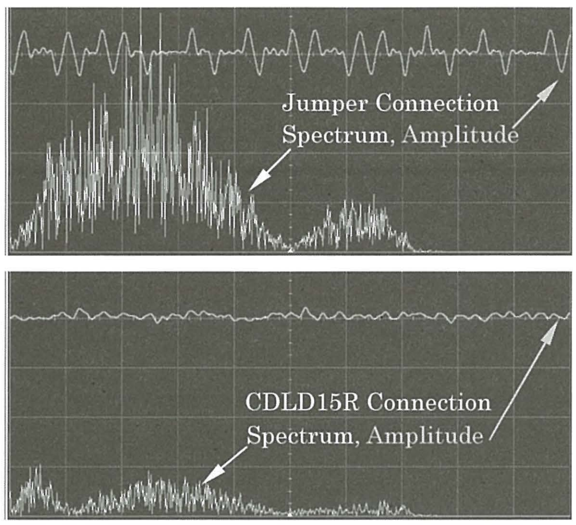
20ps/div(H), 500mV/div(V)

Fig.8 Eye-Pattern by Measurement



Amplitude: 500ps/div(H), 500mV/div(V)
Spectrum : 2GHz/div(H), 5mV/div(V)

Fig.7 Waveform and Spectrum of Common-mode Noise by Simulation



Amplitude: 500ps/div(H), 500mV/div(V)
Spectrum : 2GHz/div(H), 5mV/div(V)

Fig.9 Waveform and Spectrum of Common-mode Noise by Measurement

Since measurement and simulation show good coincidence, the validity of the measured result is acceptable. Further, by comparing the CDLD15R connection with a jumper connection, it is shown that the CDLD15R is very effective in removing common-mode noise in 10Gbps operation.

V. Eye-pattern Improvement

Another measurement was performed in order to verify improvement of the differential signal eye-pattern.

Fig. 10 is an outline view of a test board prepared for this purpose. This generates a GND discontinuity and a large skew in order to degrade the eye pattern. Either a jumper or a CDLD15R is connected to the portion displayed as Part A and Part B.

Fig. 11 shows the equivalent circuit for verifying eye-pattern improvement using the above-mentioned test board. The circuit simulation was performed with this circuit and measurements were taken using this test board.

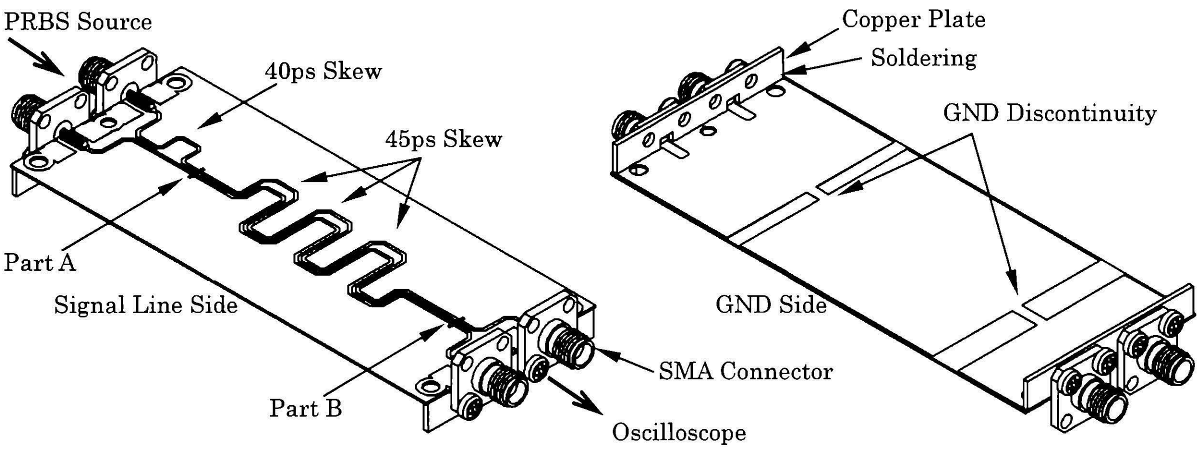


Fig.10 Outline View of Test Board for Verification of Eye-pattern Improvement

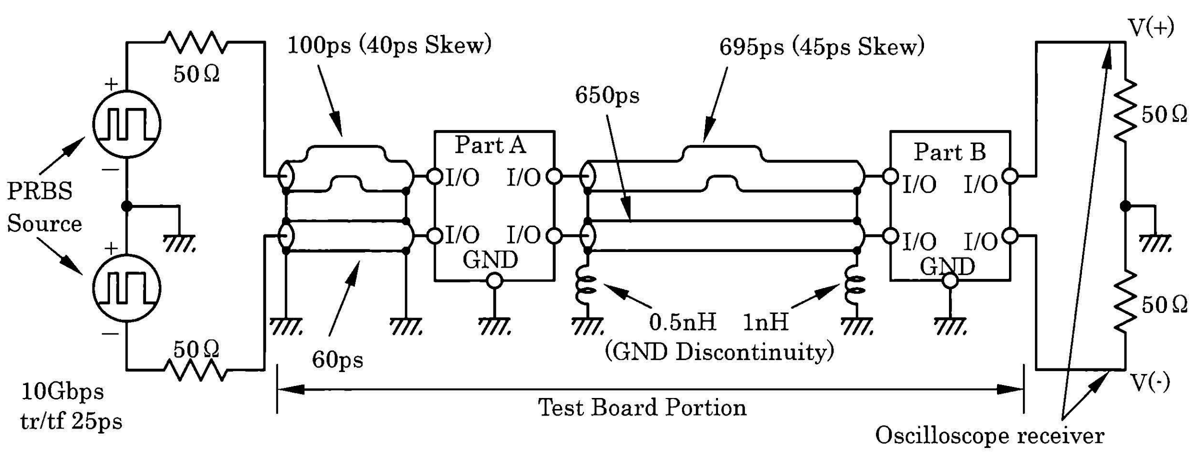


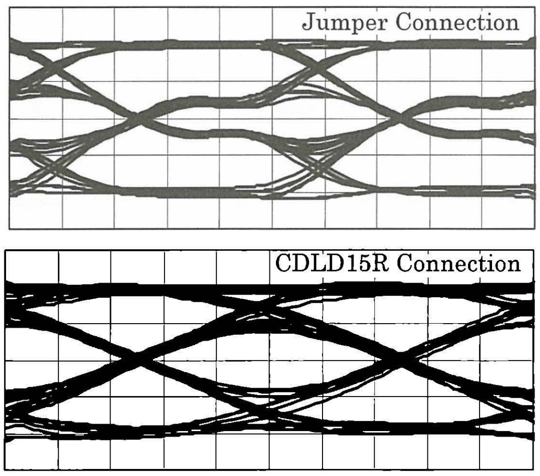
Fig.11 Equivalent Circuit for Verification of Eye-pattern Improvement

Fig.12 shows a differential output signal eye-pattern for a CDLD15R or a jumper connection by circuit simulation. In this case, the same parts are connected to both Part A and Part B within one test board.

Fig.13 shows waveforms and spectrums of the output common-mode noise corresponding to the above conditions.

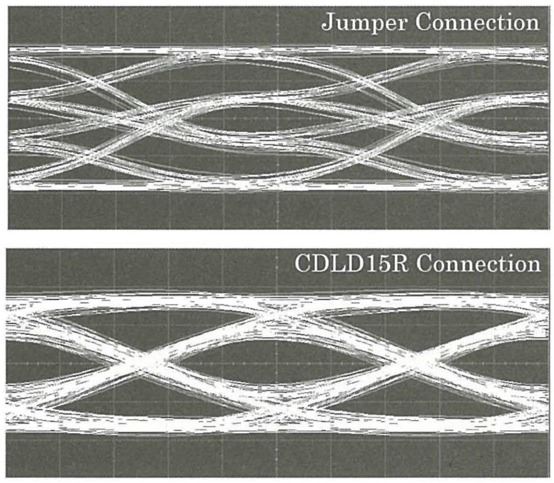
Fig. 14 and Fig. 15 show the actual measurement results corresponding to Fig. 12 and Fig. 13, respectively.

By comparing the CDLD15R connection with the jumper connection, it is shown that the CDLD15R is very effective in improving a differential signal eye-pattern at 10Gbps operation.



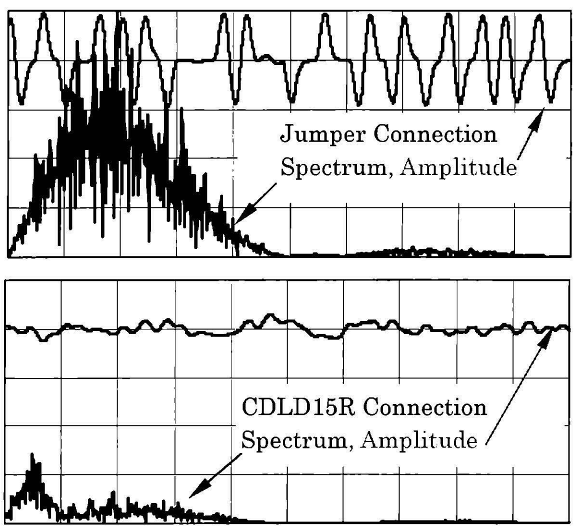
20ps/div(H), 500mV/div(V)

Fig.12 Eye-Pattern by Simulation



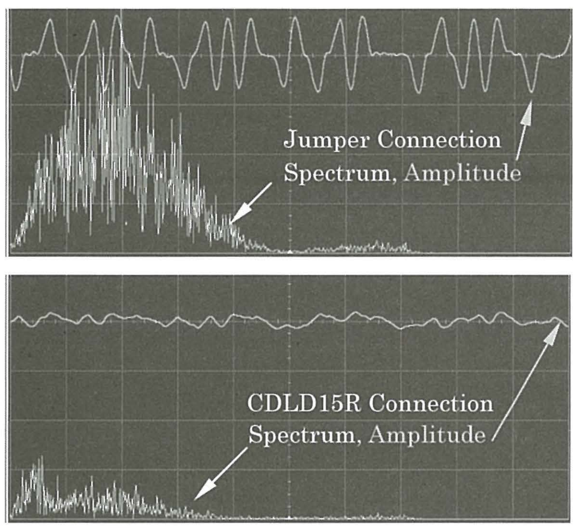
20ps/div(H), 500mV/div(V)

Fig.14 Eye-Pattern by Measurement



Amplitude: 500ps/div(H), 500mV/div(V)
Spectrum : 2GHz/div(H), 10mV/div(V)

Fig.13 Waveform and Spectrum of Common-mode Noise by Simulation



Amplitude: 500ps/div(H), 500mV/div(V)
Spectrum : 2GHz/div(H), 10mV/div(V)

Fig.15 Waveform and Spectrum of Common-mode Noise by Measurement

VI. EMI Radiation Noise

Since a CDLD-type absorbs common-mode noise, it is effective in prevention of EMI radiation noise. Measurement of this radiation noise utilizing the test board of Fig. 10 was performed.

Fig. 16 shows the measurement and radiation noise environment and the test board settings in the 3m anechoic chamber installed in Shimane Institute for Industrial Technology. A test board is held vertically and the PRBS signal is applied.

Fig. 17 shows the EMI radiation noise spectrum for a 10Gbps PRBS signal.

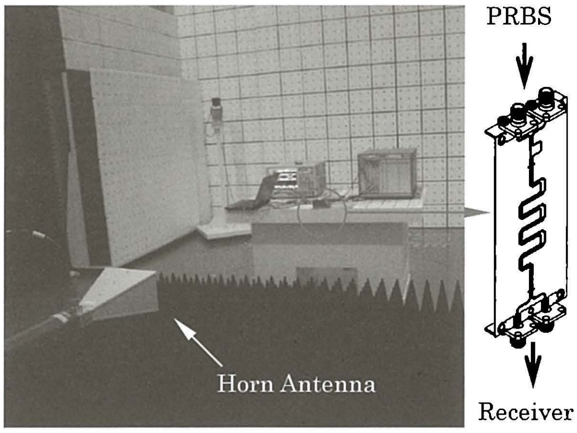


Fig.16 3m Anechoic Chamber for EMI Radiation Noise Measurement

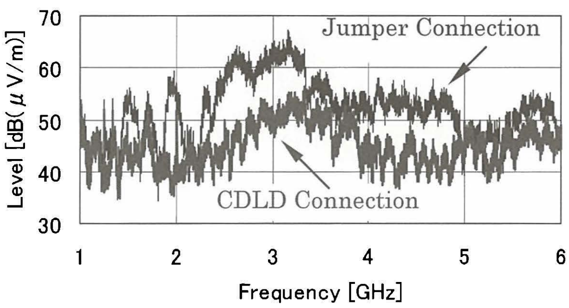


Fig.17 EMI Radiation Noise at 10Gbps (1GHz～6GHz : Vertical Polarization)

It plots both the CDLD connection and the jumper connection. Sufficient noise radiation prevention effect is acquired as shown in the figure.

Next, in order to verify the noise absorption effect of the CDLD15R, it is compared with a common-mode choke coil connected to both Part A and Part B of the test board. Signal speed is 5 Gbps so that a commercial USB3.0 common-mode choke coil can respond.

Fig. 18 shows the EMI radiation noise spectrum for a 5Gbps PRBS signal.

It is shown that the CDLD15R is more effective in the prevention of noise radiation than a common-mode choke coil.

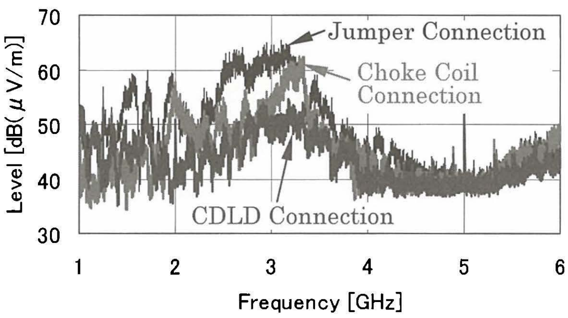


Fig.18 EMI Radiation Noise at 5Gbps (1GHz～6GHz : Vertical Polarization)

VII. CONCLUSIONS

A common-mode filter for transmission speeds exceeding 10Gbps is realized using a new principle. It is produced with a 2.0mm×1.2mm footprint and is an LTCC product. A trial production sample is measured and the sufficient effects of eye-pattern improvement and noise rejection for 10Gbps operation are shown.

Furthermore, radiation noise is measured and sufficient radiation prevention effectiveness is verified.

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