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TECHNICAL SPECIFICATION

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AMENDMENT 1

Metallic communication cable test methods –
Part 4-1: Electromagnetic compatibility (EMC) – Introduction to electromagnetic screening measurements

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FOREWORD

This amendment has been prepared by IEC technical committee 46: Cables, wires, waveguides, RF connectors, RF and microwave passive components and accessories.

The text of this amendment is based on the following documents:

DTS	Report on voting
46/726/DTS	46/748/RVDTS

Full information on the voting for the approval of this amendment can be found in the report on voting indicated in the above table.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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2 Normative references

Add to the following reference to Clause 2:

IEC 62153-4-9, *Metallic communication cable test methods – Part 4-9: Electromagnetic compatibility (EMC) – Coupling attenuation of screened balanced cables, triaxial method*

Figure 86 – Principle test set-up for measuring the coupling attenuation of screened balanced or multipin connectors

Insert the following note before the title:

NOTE The balun transformer is not required in case of multiport VNA with mixed mode capabilities, see Annex A.

Add, after Clause 12, the following new Annexes A and B:

Annex A
(normative)

Mixed mode S-parameter

A.1 General

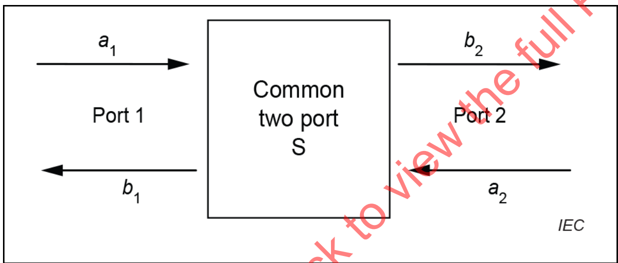
To measure the parameters like unbalance attenuation, coupling attenuation etc. of balanced cables, connectors and components, a differential signal is required. This can, for example, be generated by using a balun which converts the unbalanced signal of a 50 Ω network analyser into a balanced signal.

Alternatively, a balanced signal may be obtained by using a vector network analyser (VNA) having two generators with a phase shift of 180°. Another alternative is to measure with a multi-port VNA (virtual balun).

The properties of balanced pairs are determined mathematically from the measured values of each single conductor of the pair against reference ground. The coverable frequency range for the determination of the reflection and transmission characteristics of symmetrical pairs is no longer limited by the balun but by the VNA and the connection technique.

A.2 Definition of mixed mode S-parameters

The transmission characteristics of four poles or two ports, such as coaxial cables, may be described by the scattering parameter or abbreviated “S-parameter”, see Figure A.1. In matrix notation it is written:

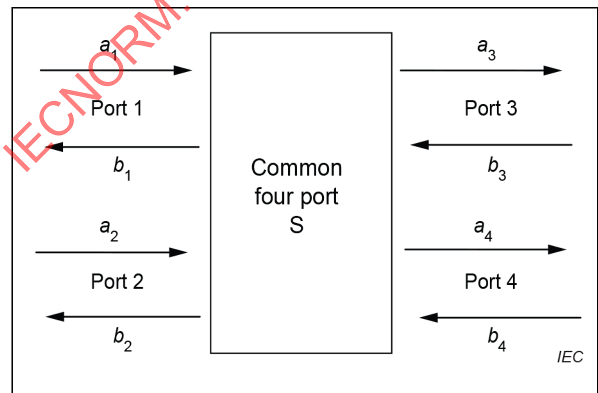


$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = (S) \cdot \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \cdot \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} \quad \text{(A.1)}$$

where *a* and *b* are the normalized power waves of the input and output ports.

Figure A.1 – Common two-port network

The definition of the scattering matrix can be easily extended to arbitrary N gates, see Figure A.2. For a four-port, this results in:



$$\begin{pmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{pmatrix} = \left(S^{\text{std}}\right) \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{43} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{pmatrix} \cdot \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{pmatrix} \quad \text{(A.2)}$$

Figure A.2 – Common four port network

A.3 Mixed mode S-parameter nomenclature

For the measurement of symmetrical two-ports, the physical ports of the multi-port VNA are combined into logical ports, see Figure A.3:

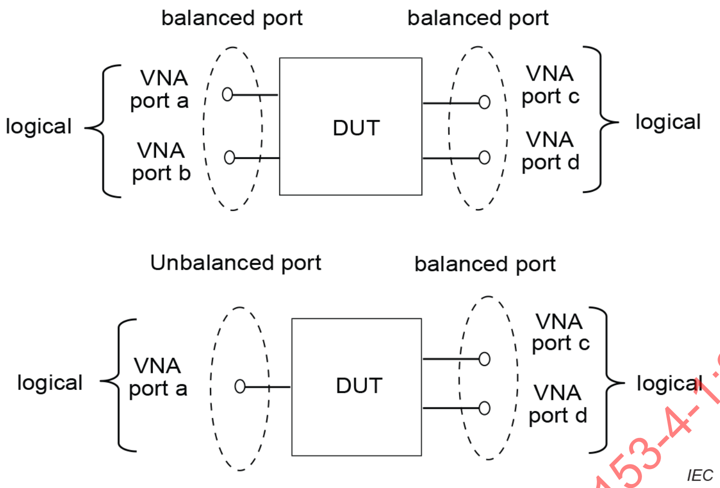
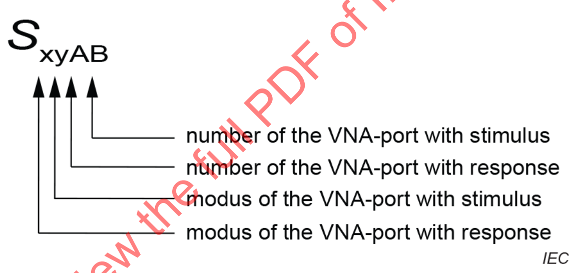


Figure A.3 – Physical and logical ports of a VNA

According to Figure A.4, the following nomenclature is used:



Modus	s: Single ended
	d: Differential mode
	c: Common mode

Figure A.4 – Nomenclature of mixed mode S-parameters

Accordingly, the S-parameters can be understood as ratios of power waves.

$$S_{xyAB} = \frac{\mathit{input\ signal\ at\ VNA\text{-}port\ A\ at\ modus\ x}}{\mathit{input\ signal\ at\ VNA\text{-}port\ B\ at\ modus\ y}} \tag{A.3}$$

The conversion of the asymmetrical four-port scattering parameters S^{std} to mixed mode scattering parameters S^{mm} for a symmetrical two-port network is given by:

$$S^{mm} = M \times S^{std} \times M^{-1} \tag{A.4}$$

where

$$M = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{bmatrix} \tag{A.5}$$

$$S^{mm} = \begin{bmatrix} \begin{bmatrix} S_{dd11} & S_{dd12} \\ S_{dd21} & S_{dd22} \end{bmatrix} & \begin{bmatrix} S_{dc11} & S_{dc12} \\ S_{dc21} & S_{dc22} \end{bmatrix} \\ \begin{bmatrix} S_{cd11} & S_{cd12} \\ S_{cd21} & S_{cd22} \end{bmatrix} & \begin{bmatrix} S_{cc11} & S_{cc12} \\ S_{cc21} & S_{cc22} \end{bmatrix} \end{bmatrix} \tag{A.6}$$

The derivation of the mixed mode parameters (Formulae (A.4) to (A.6)) is described in Annex B.

For the measurement of a two-port with an unbalanced port (single ended) and a balanced port, e.g. to measure coupling attenuation according to IEC 62153-4-5 or to IEC 62153-4-9, the measurement configurations according to Table A.1 arise:

Table A.1 – Measurement configurations unbalanced – balanced

			Stimulus		
			Single ended	Differential mode	Common mode
			Logical port 1	Logical port 2	Logical port 2
Response	Single ended	Logical port 1	S_{ss11}	S_{sd12}	S_{sc12}
	Differential mode	Logical port 2	S_{ds21}	S_{dd22}	S_{dc22}
	Common mode	Logical port 2	S_{cs21}	S_{cd22}	S_{cc22}

The measurement of the coupling attenuation corresponds to a stimulus in the differential mode and to a response in the unbalanced (coaxial) mode (single ended), i.e. a measurement of the S-parameter S_{sd12}. The measurement of the screening attenuation corresponds to a stimulus in the common mode and to a response in the unbalanced (coaxial) mode (single ended), i.e. a measurement of the S-parameter S_{sc12}, see Figure A.5.

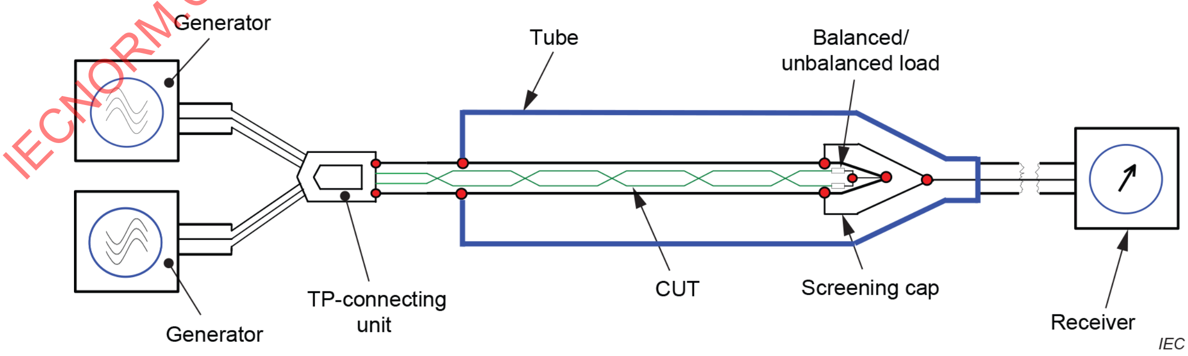


Figure A.5 – Balunless measuring of coupling attenuation, principle set-up with multiport VNA and standard head

For the measurement of a two-port, the test configurations according to Table A.2 are obtained:

Table A.2 – Measurement configurations balanced – balanced

			Stimulus			
			Differential mode		Common mode	
			Logical port 1	Logical port 2	Logical port 1	Logical port 2
Response	Differential mode	Logical port 1	S_{dd11}	S_{dd12}	S_{dc11}	S_{dc12}
		Logical port 2	S_{dd21}	S_{dd22}	S_{dc21}	S_{dc22}
	Common mode	Logical port 1	S_{cd11}	S_{cd12}	S_{cc11}	S_{cc12}
		Logical port 2	S_{cd21}	S_{cd22}	S_{cc21}	S_{cc22}

The measurement of the attenuation of a balanced pair corresponds to a stimulus and a response in differential mode, i.e. a measurement of the S-parameter S_{dd21}. The measurement of the unbalance attenuation with stimulus in differential mode and common mode response corresponds at the near end with the S-parameter S_{cd11} or S_{cd21} when measured at the far end.

A.4 Termination

A differential mode termination according to Figure A.6 and Figure A.7 is required for each pair at the near and far end of the cable.

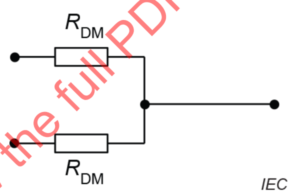


Figure A.6 – Termination network

$$R_{DM} = \frac{Z_{diff}}{2} \tag{A.7}$$

The termination of the common mode is 25 Ω (R_{CM} = 0).

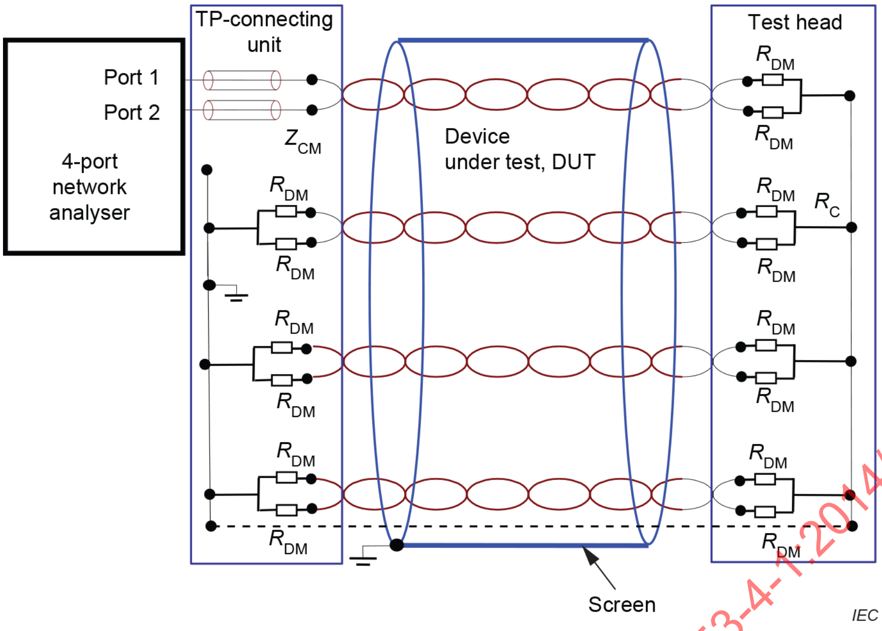


Figure A.7 – Termination of a screened symmetrical cable, principle

NOTE Since mixed mode VNAs use a 50 Ω generator and receiver impedance as default value, the common mode value results in 25 Ω.

A.5 Reference impedance of a VNA

When measuring with a 4 port VNA with mixed mode parameters, a full 4-port calibration, e.g. with electronic calibration units shall be applied. The VNA (Z_0 = 50 Ω physical analyser ports) sets the default values reference impedances for the differential mode Z_{0d} = 100 Ω (= 2 × Z_0) and for the common mode Z_{0c} = 25 Ω (= Z_0/2).

A.6 TP-connecting unit

When measuring balunless respectively with “virtual balun”, a TP connecting unit is required. The TP-connecting unit performance requirements are given in Table A.3.

Table A.3 – TP-connecting unit performance requirements (100 kHz to 2 GHz)

Parameter	Value
Characteristic impedance, primary side (single ended)[a]	50 Ω
Characteristic impedance, secondary side (differential)[a]	1 × 100 Ω (differential)
Return loss, differential mode[b]	> 20 dB
Attenuation, differential mode[c]	< 0,3 dB
Unbalance attenuation (TCTL)[d]	> 60 dB-10*log (*f*), 40 dB max.

[a] Two ports with single ended impedances of 50 Ω generate a common mode impedance of 25 Ω and a differential mode impedance of 100 Ω.

[b] To be measured e.g. with a 4 port mixed mode network analyser. One logical port is generated by the combination of two single ended ports. A second logical port is generated by the combination of two other single ended ports. The absolute dB value of the S-parameter S_{dd11} then represents the return loss of the differential mode.

NOTE With the test set-up according to b), the absolute dB value of the S-parameter S_{cd11} then represents the unbalance attenuation (TCL). The TP connecting unit is used also for the measurement of coupling attenuation.

[c] With the test set-up according to b), the absolute dB value of the S-parameter S_{dd21} then represents the attenuation of the differential mode.

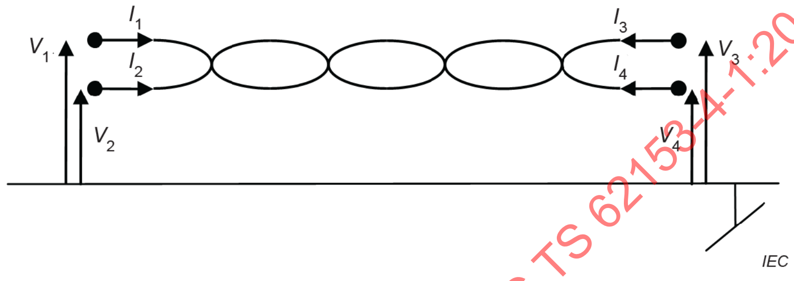
[d] With the test set-up according to b), the absolute dB value of the S-parameter S_{cd21} then represents the unbalance attenuation (TCTL).

Annex B
(informative)

Example derivation of mixed mode parameters using the modal decomposition technique

It is not a requirement of this document that a full derivation is produced, and any method of extracting the required S-parameters is acceptable. This may be achieved by the use of network analyser hardware functions, specific mathematical software, or by circuit simulation tools.

Annex B presents a summary of how to derive mixed mode parameters from 4-port measurements of S-parameters, where *V* is the voltage and *I* is the current, see Figure B.1:



Key

V voltage

I current

Figure B.1 – Voltage and current on balanced cable or cabling under test (CUT)

An impedance matrix (Z) of the cable or cabling under test (CUT) can be calculated based on Equation (B.1).

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & Z_{13} & Z_{14} \\ Z_{21} & Z_{22} & Z_{23} & Z_{24} \\ Z_{31} & Z_{32} & Z_{33} & Z_{34} \\ Z_{41} & Z_{42} & Z_{43} & Z_{44} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} \qquad \text{(B.1)}$$

The modal domain impedance matrix [Z^{m}] is then calculated from Equation (B.2) below, using the conversion matrices given in Equation (B.3) and Equation (B.4).

$$Z^{\mathrm{m}} = P_{\mathrm{e}}^{-1} Z Q_{\mathrm{e}} \qquad \text{(B.2)}$$

$$P_e^{-1} = \begin{bmatrix} P^{-1} & 0 \\ 0 & P^{-1} \end{bmatrix} \qquad \text{(B.3)}$$

$$Q_e = \begin{bmatrix} Q & 0 \\ 0 & Q \end{bmatrix} \qquad \text{(B.4)}$$

In the case of a 1 pair cable or cabling under test (CUT), the size of the conversion matrices becomes 4 × 4 with the values given in Equation (B.5) and Equation (B.6).

$$P = \begin{bmatrix} \frac{1}{2} & 1 \\ -\frac{1}{2} & 1 \end{bmatrix} \tag{B.5}$$

$$Q = \begin{bmatrix} 1 & \frac{1}{2} \\ -1 & \frac{1}{2} \end{bmatrix} \tag{B.6}$$

The conversion matrices replace the Balun transformers and are referred to as mathematical baluns, producing Equation (B.7) and Equation (B.8).

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} = P_e \begin{bmatrix} V_{D1} \\ V_{C1} \\ V_{D2} \\ V_{C2} \end{bmatrix} \tag{B.7}$$

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = Q_e \begin{bmatrix} I_{D1} \\ I_{C1} \\ I_{D2} \\ I_{C2} \end{bmatrix} \tag{B.8}$$

Substituting Equation (B.7) and Equation (B.8) into Equation (B.1), we obtain Equation (B.9), which is equivalent to a set of hybrid transformers attached at each end of the cable pair as described in Figure B.2.

$$\begin{bmatrix} V_{D1} \\ V_{C1} \\ V_{D2} \\ V_{C2} \end{bmatrix} = \begin{bmatrix} Z^m_{11} & Z^m_{12} & Z^m_{13} & Z^m_{14} \\ Z^m_{21} & Z^m_{22} & Z^m_{23} & Z^m_{24} \\ Z^m_{31} & Z^m_{32} & Z^m_{33} & Z^m_{34} \\ Z^m_{41} & Z^m_{42} & Z^m_{43} & Z^m_{44} \end{bmatrix} \begin{bmatrix} I_{D1} \\ I_{C1} \\ I_{D2} \\ I_{C2} \end{bmatrix} \tag{B.9}$$

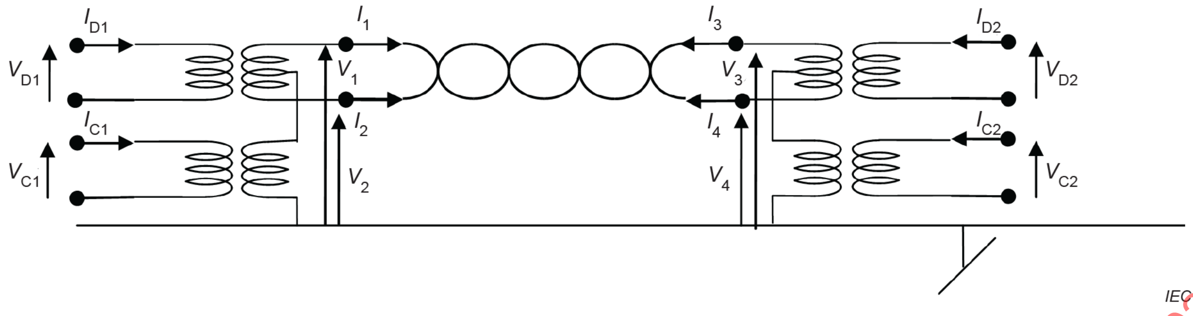


Figure B.2 – Voltage and current on unbalanced DUT

For the measurements concerned in this document, S-parameters are measured and converted into Z-parameters. The Z-parameter matrix of a 2n-port circuits can be derived using Equation (B.10).

$$Z = R^{\frac{1}{2}}\left[E+S\right]\left[E-S\right]^{-1}R^{\frac{1}{2}} \tag{B.10}$$

where E is a $2n \times 2n$ unit matrix and $R^{\frac{1}{2}}$ is given by Equation (B.11).

$$R^{\frac{1}{2}} = \begin{bmatrix} \sqrt{r_1} & 0 & \dots & 0 \\ 0 & \sqrt{r_2} & 0 & M \\ M & 0 & 0 & 0 \\ 0 & \dots & 0 & \sqrt{r_{2n}} \end{bmatrix} \tag{B.11}$$

Where r_x is the impedance of the measurement port, typically 50 Ω, giving Equation (B.12).

$$R^{\frac{1}{2}} = \begin{bmatrix} \sqrt{50} & 0 & \dots & 0 \\ 0 & \sqrt{50} & 0 & M \\ M & 0 & 0 & 0 \\ 0 & \dots & 0 & \sqrt{50} \end{bmatrix} \tag{B.12}$$

The S-parameters in the modal domain are then calculated using Equation (B.13), giving Equation (B.14).

$$S^{m} = R_{m}^{-\frac{1}{2}}\left[Z^{m} - R_{m}\right]\left[Z^{m} + R_{m}\right]^{-1}R_{m}^{\frac{1}{2}} \tag{B.13}$$

$$R_{m}^{\frac{1}{2}} = \begin{bmatrix} \sqrt{r_{m1}} & 0 & \dots & 0 \\ 0 & \sqrt{r_{m2}} & 0 & M \\ M & 0 & 0 & 0 \\ 0 & \dots & 0 & \sqrt{r_{m2n}} \end{bmatrix} \tag{B.14}$$

By this method, it is possible to convert unbalance network analyser measurements into mixed mode S-matrices which contain both balanced and unbalanced parameters, as in Equation (B.15).

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} \Rightarrow \begin{bmatrix} S_{\mathrm{DD11}} & S_{\mathrm{DC11}} & S_{\mathrm{DD12}} & S_{\mathrm{DC12}} \\ S_{\mathrm{CD11}} & S_{\mathrm{CC11}} & S_{\mathrm{CD12}} & S_{\mathrm{CC12}} \\ S_{\mathrm{DD21}} & S_{\mathrm{DC21}} & S_{\mathrm{DD22}} & S_{\mathrm{DC22}} \\ S_{\mathrm{CD21}} & S_{\mathrm{CC21}} & S_{\mathrm{CD22}} & S_{\mathrm{CC22}} \end{bmatrix} \tag{B.15}$$