Mode Transformation for 40GBASE-R and 100GBASE-R

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Overview

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- Effect of mode transformation
- Related analytical results
- Conclusion
- Related description in 802.3ba(Draft1.2)
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- References

Background

- See details in W.Fan,A.C.W.Lu,L.L.Wai and B.K.Lok, Mixed-Mode S-parameter Characterisation of Differential Structures, STR/04/011/JT,p. 66-70

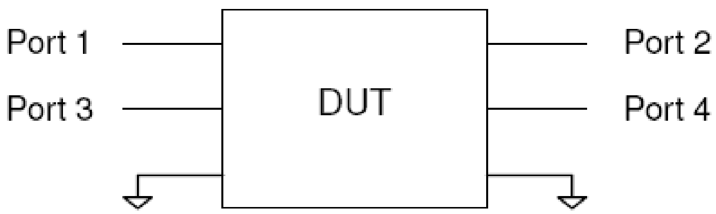


Diagram of single-ended 4-port DUT

$$B_{std} = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} \qquad A_{std} = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix}$$

$$S_{std} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}$$

- The relationship between the power waves is shown as: $B_{std}=S_{std}\cdot A_{std}$.
- B_{std} and A_{std} represents response and stimulus waves' matrix respectively; whereas S_{std} is the standard four-port s-parameters matrix.

Background Cont.

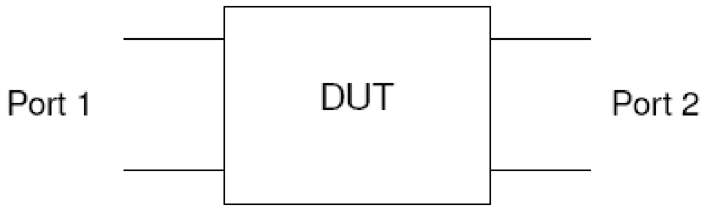


Diagram of differential 2-port DUT

$$B_{mm} = MB_{std}$$

$$= \begin{bmatrix} b_{d1} \\ b_{d2} \\ b_{c1} \\ b_{c2} \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix}$$

$$A_{mm} = MA_{std}$$

$$= \begin{bmatrix} a_{d1} \\ a_{d2} \\ a_{c1} \\ a_{c2} \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix}$$

$$S_{mm} = \left[\begin{array}{cc|cc} S_{d1d1} & S_{d1d2} & S_{d1c1} & S_{d1c2} \\ S_{d2d1} & S_{d2d2} & S_{d2c1} & S_{d2c2} \\ \hline S_{c1d1} & S_{c1d2} & S_{c1c1} & S_{c1c2} \\ S_{c2d1} & S_{c2d2} & S_{c2c1} & S_{c2c2} \end{array}\right]$$

- The above relationship can be shown as: $B_{mm} = S_{mm} \cdot A_{mm}$.
- B_{mm} and A_{mm} represents mixed-mode response and incident waves' matrix respectively; whereas S_{std} is the mixed-mode s-parameters matrix.

Background Cont.

- The transformation matrix between standard s-parameters and mixed-mode s-parameters can be presented as follows.

$$S_{mm} = MS_{std}M^{-1} = \begin{bmatrix} \begin{bmatrix} S_{d1d1} & S_{d1d2} \\ S_{d2d1} & S_{d2d2} \end{bmatrix} & \begin{bmatrix} S_{d1c1} & S_{d1c2} \\ S_{d2c1} & S_{d2c2} \end{bmatrix} \\ \begin{bmatrix} S_{c1d1} & S_{c1d2} \\ S_{c2d1} & S_{c2d2} \end{bmatrix} & \begin{bmatrix} S_{c1c1} & S_{c1c2} \\ S_{c2c1} & S_{c2c2} \end{bmatrix} \end{bmatrix} \quad M = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{bmatrix} \quad M^{-1} = \frac{M^*}{|M|} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ -1 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 \end{bmatrix}$$

mode transformation

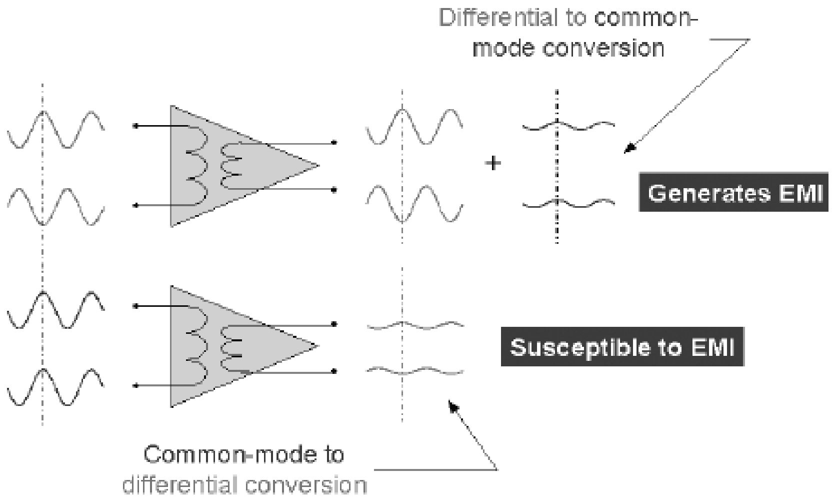
- Mode transformation is unwanted effect in high speed interconnects

$$S_{mm} = MS_{std}M^{-1} = \begin{bmatrix} \begin{bmatrix} S_{d1d1} & S_{d1d2} \\ S_{d2d1} & S_{d2d2} \end{bmatrix} & \begin{matrix} \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} \end{matrix} \\ \begin{matrix} \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} \end{matrix} & \begin{bmatrix} S_{c1c1} & S_{c1c2} \\ S_{c2c1} & S_{c2c2} \end{bmatrix} \end{bmatrix}$$

no mode transformation

Elements that cause mode transformation

- Mode transformation occurs when some of the differential signal is converted into the common mode and some of the common-mode signal is converted into the differential mode.



- Symmetry plane is the necessary and sufficient requirements of no mode transformation
- Bends and differential-pair skew usually cause the effect
- As for microstrip line, difference in the propagation velocities of odd and even mode is another reason.

Effect of mode transformation

- The higher data rate, the more effect of mode transformation. With increasing data rates and the process imperfections of manufacturing, it becomes impossible to maintain a well balanced system, thus leading to higher amounts of common mode energy in differential systems.
- Mode transformation usually occurs at non-symmetrical placement and especially the routing near via-holes.
- Common mode may cause signal degradation in time domain and especially electromagnetic emission (EMI problem).
- The effect of common mode on multigigabit-per-second Interconnects is obvious and dependent on various structures, such as different etch geometries, cables and so on.

Related analytical results

- Reducing the dimension of the bends is feasible to minimize mode transformation
- Compensating the discontinuities and skew between differential pairs is necessary to minimize mode transformation
- Structure with even mode propagation velocity as close to that of odd mode as possible can be used to reduce mode transformation
- With focuses on signal integrity and EMI issues, common mode characteristics are related to the different structures, including etch geometries, connectors, cables.
- Injecting the phase-shifted common mode signal into the transmission line can be used to cancel the undesired common mode signals.

Conclusion

- Non-symmetrical of structure and other factors such as dielectric characteristics and manufacturing errors make the structure have mode transformation.
- Mode transformation has more serious effects on EMI than signal integrity. For example, energy transformed into common modes at the non-symmetrical structure, which cause mode transformation need to be considered in high speed interconnect design.
- Based on simulation, measurement and analysis, we can derive and improve the configurations and patterns to minimize the mode transformation. By these means, the radiation is reduced, enabling the use of greater transmission power which, in turn, can provide increased transmission capacity.

Related description in 802.3ba(Draft1.2)

- The recommended limit on the differential to common-mode through response of the mated HCB and MCB, SCD12 or SCD21(which can be founded in Section 86.7.1.1), is given as follows.

The recommended limit on the differential to common-mode through response of the mated HCB and MCB is given in Equation 86–11 and shown in Figure 86–8.

$$20\times\log_{10}(|SCDij|) \begin{cases} \leq -30 + 2.91 \times f & 0.01 \leq f \leq 5.5 \\ \leq -14 & 5.5 \leq f \leq 15 \end{cases} \quad (86\text{–}11)$$

where SCD*ij* is SCD21 or SCD12 looking into the HCB or looking into the MCB, and
f is the frequency in gigahertz.

- In Table 86-6, 'AC common mode output voltage' specification is included and limited.

(Explanation: The limit of 'AC common mode output voltage' can be used to restrict the output common mode voltage, however it is not enough to be used to limit the differential to common mode transformation of transmission signal in the high speed channel design. So it is still necessary to add mode transmission specification into 802.3ba Draft1.2)

Suggestion

- Add the limit on mode transformation(SCD12 or SCD21) for 40GBASE-R and 100GBASE-R into the 802.3ba specification.

  For example, Table 85-6 is missing the limit or requirement of differential to common mode conversion SCD12 or SCD21. It is necessary to add row to Table 85-6 for SCD12 or SCD21.

  (As one of the submitted comments at March Plenary Meeting, the above suggestion, Comment 140, can be also seen at: http://www.ieee802.org/3/ba/public/mar09/P8023ba-D12_Finala_Responses_byID.pdf)

References

- Agilent Technologies,Multiport & Balanced Device Measurement Application Note Series, Concepts in Balanced Device Measurements, Application Note 1373-2
- W.Fan,A.C.W.Lu,L.L.Wai and B.K.Lok, Mixed-Mode S-parameter Characterisation of Differential Structures, STR/04/011/JT,p. 66-70
- Jason Chan, Tom Cohen, Brian Kirk, Jose Paniagua, Common Mode Effects on Multigigabit-per-second Interconnects, DesignCon 2009
- Don DeGroot, Guidelines for multiport and mixed-mode S-parameter measurements in high-speed interconnection design, DesignCon 2009

Thanks