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The common mode circuit resistance unbalance (CMCRU) calculation based on min. / max. conductor resistance values and pair–to–pair resistance unbalance measurements including loop resistance

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The present is an informal reply to a problem raised by the liaison letter from ISO/IEC JTC1/SC25/Wg3 to IEC SC46 on IEC 61156-5 to 61156-7 cables, concerning common mode resistance unbalance (CMCRU) between pairs in data grade cables, and shall be used as a base for future standardization.

It is as such forwarded to:

1.) the secretary of IEC 46
2.) the secretary of IEC 46C
3.) the chair of IEC 46C WG7
4.) the secretary of ISO/IEC JTC12/SC25 WG3
5.) the VP of ICEA – Communication cable section
6.) the liaison officer of ICEA to the ASTM D9 group
7.) the chair of TIA 42.7
8.) the chair of the PoEP task group

In fact, in view of some changes of requirements proposed in the latest versions of IEEE 802.3af and 802.3ar the following will have to be considered for future standardization.

However, it has to be clearly stressed, that the derivations given herein have to be taken not only into account for all those cables standardized in the future, but they should serve as well all those cable companies interested to work through their past production protocols in order to get an overview on the performance of the installed base, to get an overview of what limits can be reasonably specified.

1. The common mode resistance unbalance (CMCRU) based upon the resistance unbalance definitions

The following assessment of the common mode circuit resistance unbalance (CMCRU) is based upon the definition of the pair–to–pair resistance unbalance according to IEC and similar results are given also based on the pair–to–pair resistance unbalance according to ASTM D 4566-2005. In these cases the common mode circuit resistance unbalance (CMCRU) is given in terms of the maximum and minimum conductor resistance in each pair.

Alternatively the common mode circuit resistance unbalance (CMCRU) is expressed also in terms of the loop resistance and the conductor resistance unbalance of each pair

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1.1 Calculations based on the IEC definitions

1.2 Calculation based on the IEC definition and the minimum and maximum conductor resistance of each pair

a.) Assessment of all resistance unbalance measurements, using the IEC definition, i.e.:

$$CRU = \frac{R_{max} - R_{min}}{R_{max} + R_{min}} \quad (1)$$

That means the resistance of each conductor has to be measured, and then the resistance unbalance will have to be calculated.

b.) In the context described above it is mandatory for high performance data grade cables to calculate the common mode circuit resistance unbalance. This value is calculated for the 6 possible pair combinations using the following equation:

$$CMCRU_{i,k} = \frac{\left| R_{maxi} \cdot R_{min\,i} \times \left(R_{maxk} + R_{min\,k}\right) - R_{maxk} \cdot R_{mink} \times \left(R_{maxi} + R_{min\,i}\right) \right|}{R_{max\,i} \cdot R_{min\,i} \times \left(R_{maxk} + R_{mink}\right) + R_{maxk} \cdot R_{mink} \times \left(R_{max\,i} + R_{min\,i}\right)} \quad (2)$$

where the indices i and k designate the pair combination under consideration, i.e. these indices may run from 1 to 4 under the condition:

$$i \neq k \text{ and } i < k \quad (3)$$

1.3 Calculation based on the IEC definition and the loop resistance and the conductor resistance unbalance of each pair

For the loop resistances R_L of any pair combination pair we have:

$$R_{L\ i} = R_{max\ i} + R_{min\ i} \qquad \text{and:} \qquad R_{L\ k} = R_{max\ k} + R_{min\ k} \quad (4)$$

Hence we get:

$$\begin{aligned} R_{max\ i} &= R_{L\ i} \cdot \frac{1 + CRU_i}{2} \qquad \text{and:} \qquad R_{max\ k} = R_{L\ k} \cdot \frac{1 + CRU_k}{2} \\ R_{min\ i} &= R_{L\ i} \cdot \frac{1 - CRU_i}{2} \qquad \text{and:} \qquad R_{min\ k} = R_{L\ k} \cdot \frac{1 - CRU_k}{2} \end{aligned} \quad (5)$$

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Hence we get for the common mode circuit resistance unbalance (CMCRU), respecting the condition of Eq (3):

$$CMCRU_{i,k} = \left| \frac{R_{L\ i} \cdot \left(1 - CRU_i^2\right) - R_{L\ k} \cdot \left(1 - CRU_k^2\right)}{R_{L\ i} \cdot \left(1 - CRU_i^2\right) + R_{L\ k} \cdot \left(1 - CRU_k^2\right)} \right| \tag{6}$$

Obviously the CRU values have to be taken into account as straight values, not in percent.

If we assume a maximum specified value for the conductor resistance unbalance, then we get:

$$\begin{aligned} CMCRU_{i,k} &= \left(1 - CRU_{Spec}^2\right) \cdot \left| \frac{R_{L\ i} - R_{L\ k}}{R_{L\ i} + R_{L\ k}} \right| \\ &= \left(1 - CRU_{Spec}^2\right) \cdot CRL_{i,k} \end{aligned} \tag{7}$$

where CRL - is the loop resistance unbalance

As a result we see, that the CMCRU depends primarily on the loop resistance unbalance, as the first term of the right side of Eq (7) is approximately 1.

2.1 Calculation based on the ASTM definitions

2.2 Calculation based on the ASTM definition and the minimum and maximum conductor resistance of each pair

a.) The calculation of the present CRU assessment follows the definition of ASTM D 4566-2005 and may be considered for the North American customers. This definition is as follows, and yields resistance unbalance values approximately twice as high as the IEC definition:

$$CRU = \frac{R_{max} - R_{min}}{R_{min}} \tag{8}$$

b.) To use the ASTM definition of the resistance unbalance according to the ASTM D 4566-2005 definition, is slightly more awkward. The calculation yields two results, and the correct one has to be determined as follows:

First the resistance of each common mode circuit conductor (R_{CMC}) i and k (that is the conductors of each pair connected in parallel) has to be determined:

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$$R_{CMC\ i} = \frac{R_{max\ i} \cdot R_{min\ i}}{R_{max\ i} + R_{min\ i}} \qquad R_{CMC\ k} = \frac{R_{max\ k} \cdot R_{min\ k}}{R_{max\ k} + R_{min\ k}} \tag{9}$$

Then the calculation of the two possible solutions I and II continues:
For:

$$R_{CMC\ i} \leq R_{CMC\ k} \tag{10}$$

We have

$$CMCRU_I = CMCRU_{CMC\ i,k} = \frac{R_{max\ k} \cdot R_{min\ k} \times \left(R_{max\ i} + R_{min\ i}\right)}{R_{max\ i} \cdot R_{min\ i} \times \left(R_{max\ k} + R_{min\ k}\right)} - 1 \tag{11}$$

For:

$$R_{CMC\ i} \geq R_{CMC\ k} \tag{12}$$

We have

$$CMCRU_{II} = CMCRU_{CMC\ i,k} = \frac{R_{max\ i} \cdot R_{min\ i} \times \left(R_{max\ k} + R_{min\ k}\right)}{R_{max\ k} \cdot R_{min\ k} \times \left(R_{max\ i} + R_{min\ i}\right)} - 1 \tag{13}$$

2.3 Calculation based on the ASTM definition and the loop resistance and the conductor resistance unbalance of each pair

For the loop resistances R_L of any pair combination pair we have as in Eq (4):

$$R_{L\ i} = R_{max\ i} + R_{min\ i} \quad \text{and :} \quad R_{L\ k} = R_{max\ k} + R_{min\ k} \tag{14}$$

Hence we get:

$$\begin{aligned} R_{max\ i} &= R_{L\ i} \cdot \frac{1 + CRU_i}{2 + CRU_i} \quad \text{and :} \quad R_{max\ k} = R_{L\ k} \cdot \frac{1 + CRU_k}{2 + CRU_k} \\ R_{min\ i} &= R_{L\ i} \cdot \frac{1}{2 + CRU_i} \quad \text{and :} \quad R_{min\ k} = R_{L\ k} \cdot \frac{1}{2 + CRU_k} \end{aligned} \tag{15}$$

Hence we get for the condition according to Eq (10):

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$$CMCRU_{i,k} = \frac{R_{Lk}}{R_{Li}} \cdot \left(\frac{1 + CRU_k}{1 + CRU_i} \right) \cdot \left(\frac{2 + CRU_i}{2 + CRU_k} \right)^2 - 1 \qquad (16)$$

And for the condition according to Eq (12):

$$CMCRU_{i,k} = \frac{R_{Li}}{R_{Lk}} \cdot \left(\frac{1 + CRU_i}{1 + CRU_k} \right) \cdot \left(\frac{2 + CRU_k}{2 + CRU_i} \right)^2 - 1 \qquad (17)$$

The programming of this common mode circuit resistance unbalance is definitely more cumbersome and should be implemented only if there is a real customer demand expected in North America.

Again under maximum specified conductor resistance unbalance beween all pairs we get

$$CMCRU_{i,k} = \frac{R_{Lk} - R_{Li}}{R_{Li}}$$
$$CMCRU_{i,k} = \frac{R_{Li} - R_{Lk}}{R_{Lk}} \qquad (18)$$

for the conditions according to the EQs (10) and (12), respectively. Hence we get two different common mode circuit resistance unbalances, as before, but based upon the Loop resistances of the considered pair combination.

Note: PoE and PoEP are implemented by IEEE 802.3af and IEEE 802.3ar respectively, both being international organizations, and as such following IEC rules. TIA may follow the ASTM definition though.

The implementation of these additional calculations of already implemented measurements should be done ASAP, in order to assess future cables design options to comply to emerging requirements.

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