CT452/3 Busbar Design

1 Abstract

This application note covers the design and operational principle of a serpentine-style busbar. Airgap spacing is the most critical parameter followed by slit-to-slit distance and finally the actual slit width.

2 Introduction

The CT452 and CT453 are Tunnel Magnetoresistance (TMR) based, contactless, coreless, and differential current sensors. The only difference between the CT452 and CT453 is the operating voltage; the CT452 operates from a 5 V supply while the CT453 operates from 3.3 V. Otherwise, the operating and electrical characteristics are identical. This application note references the CT452 but also applies to the CT453.

- ***Contactless:*** or non-intrusive, the sensor is placed over the current conductor (Printed Circuit Board [PCB] or Busbar).

- ***Coreless:*** it does not require the use of a magnetic concentrator/shield.

- ***Differential:*** it features two (2) internal TMR sensors able to measure a differential field and reject any common mode external field.

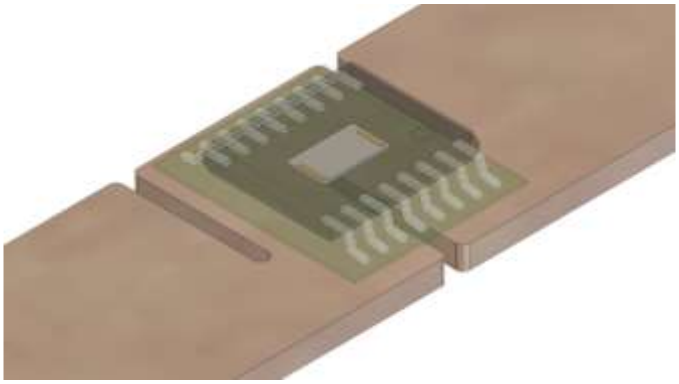

Figure 1 *CT452/3 on Serpentine-style Busbar*

The advent of electric vehicles and renewable energy has spearheaded the need for accurate and reliable current sensing in applications such as inverters for both on-board AC/DC and DC/DC fast chargers, as well as HVDC transmission systems. These and other high current applications have demonstrated the need for cost effective, high-accuracy current sensors capable of monitoring currents in the range of 50 A to greater than 1000's of Amperes.

The CT452/3 is based on patented XtremeSense® TMR technology, well suited for high current applications. The sensor benefits from a high 1:4000 Signal-to-Noise Ratio (SNR) as demonstrated with previous Crocus Technology current sensors, allowing for resolutions in the 100's of mA while measuring up to 1000's of Amperes.

This application note introduces the concept of adding busbar slits for generating a localized differential magnetic field with a maximum coupling coefficient.

3 Operating Principle

The CT452/3 is a differential magnetic field sensor designed for high CMFR (Common Mode Field Rejection) capabilities. Two (2) integrated TMR sensors are positioned in the package to detect a differential magnetic field generated by the three (3) slits on the current carrying busbar (Figure 1). The dual TMR sensors expect equal and opposite magnetic fields and therefore will reject externally generated unidirectional fields.

Each TMR sensor is a full Wheatstone bridge with a 0.70 mm separation (Figure 2).

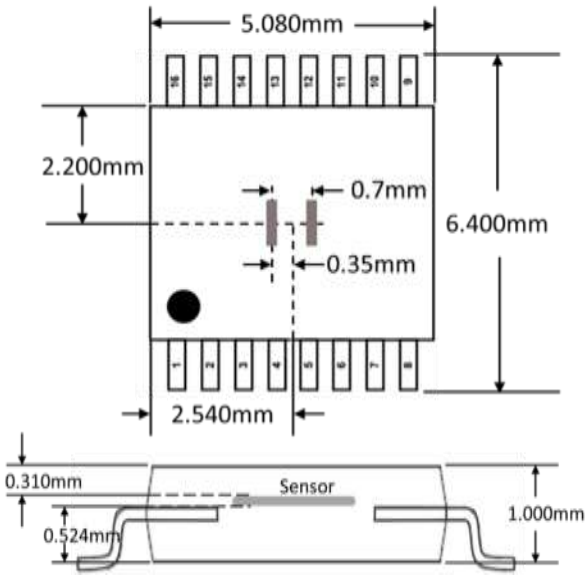

Figure 2 *TMR Sense Elements' Positions*

The CT452/3 also integrates signal conditioning circuits that output the difference of the two (2) TMR bridge outputs with a factory trimmed gain setting.

$$V_{OUT} = Gain * (B_R - B_L)$$

Where B_R and B_L are the right and left TMR sensor voltage outputs respectively.

The V_{OUT} equation can be modified to include an external field ε detected on both bridge sensors, as shown below. With CMFR, this external field ε is essentially cancelled as long as both TMR sensors detect the same external field magnitude and direction:

$$V_{OUT} = Gain * ((B_R + \varepsilon) - (B_L + \varepsilon))$$

Note that magnetic fields generated by the primary current may not be detected identically if the busbar slit position is out of alignment with the 0.70 mm distance between TMR sensor bridges. This leads to a reduction in the coupling coefficient which reduces the gain of the current sensing system. Refer to section 5, Total System Accuracy, for an explanation of the impact of mechanical tolerances.

The current carrying conductor (busbar or PCB trace) requires three (3) slits to create a "U-shape" current flow to generate a differential (B_L and B_R) field as shown in Figure 3.

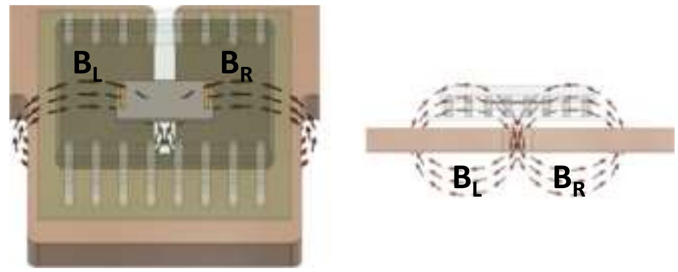

Figure 3 *U-shape Busbar, CT452/3 and the differential magnetic field lines*

3.1 Busbar Design Guidelines

In practice, instead of designing a U-shaped busbar, it is easier to begin with a standard, rectangular, busbar then machine in three slits to design the "serpentine" shape required for generating a differential field.

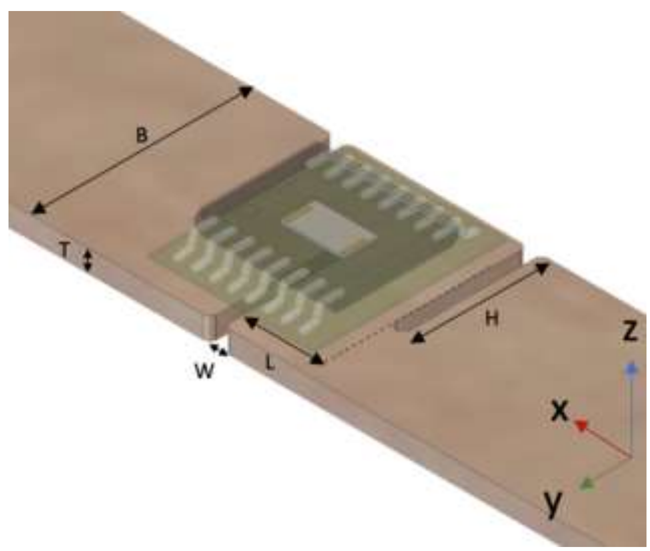

Figure 4. *CT452/3 on a serpentine shaped busbar*

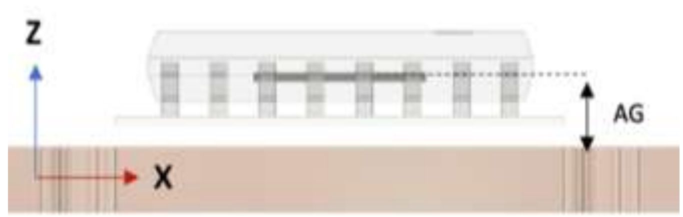

Figure 5. *Side-view of a CT452/3 on top of a busbar*

Figures 4 and 5 identify the key parameters of **AG**: Airgap, **W**: Slit width, **L**: Slit length (separation), **H**: Slit height, **T**: Busbar thickness, and **B**: Busbar width. Figures 9, 10, 11 and 12 show COMSOL® simulation results for different busbar thickness (T), slit height (H), and airgap (AG) values.

Each graph shows how the slit width (W) and slit length (L) impacts the coupling coefficient. The busbar width (B) is not a critical parameter for the coupling coefficient, therefore figures 9 to 12's simulation results assume a busbar width of 12 mm. However, the slit height (H) needs to be greater than half the busbar width (B).

Figure 13 shows the impact of linear displacement and Figure 14 shows the impact of tilt on the coupling coefficient with a variable slit width (W) and length (L). To illustrate coupling coefficient losses, six (6) axes of movement are evaluated, two (2) axes of lateral displacement, vertical displacement (i.e., airgap) and three (3) axes of tilt.

The graphs clearly indicate that given all the dimensions, the best performance is achieved with a minimal Airgap (AG) distance.

4 Eval Board Busbar Example

The CTD452/3 evaluation board (see Figure 6) includes a copper busbar. The busbar has a current density of 20 A/mm^2, a cross-sectional width of 12.70 mm (B) and 1.55 mm thick (T) for a current carrying capability of up to ±400 A.

With a busbar width of 12.70 mm (B), then the absolute minimum slit height (H) is 12.70 mm ÷ 2 = 6.35 mm. The final selected slit size is 7.35 mm providing a 1.00 mm margin to facilitate mechanical Y displacement. The slit height dimension needs to be larger than half the busbar width.

The coupling coefficient based on the above parameters is 3.9 µT/A which using the CT452-H06MRTS16 with a bipolar magnetic field detection of ±6 mT and a sensitivity of 333.3 mV/mT generates a V_{OUT} signal of 1.30 mV/A (333.3 mV / 1000 µT * 3.9 µT).

Figure 6. *CTD452/3 with busbar mounted on the bottom*

The total dynamic range of the sensor is ±1500 A. The resolution of this system will be slightly better than 1 A as the noise of the sensor over 100 kHz bandwidth (BW) is rated at 2.77 µT.

In this example, the busbar is placed under the PCB. Hence, the distance between the TMR sense elements and the busbar is the PCB thickness of 1.55 mm plus 1.05 mm to the top of the package. The die is 0.30 mm from the top of the package, the final position is then 2.30 mm.

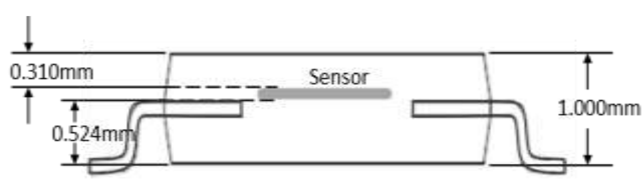

Figure 7. *TMR sensor element position inside the package*

5 Total System Accuracy

Three factors which impact the total system accuracy are:

- CT452/3 sensor accuracy
- Mechanical tolerances
- Busbar design

Every CT452/3 is factory trimmed and calibrated. The data sheet's Electrical Characteristic (EC) table shows the gain, offset and linearity error specifications along with their drift specifications over temperature and lifetime.

Busbar manufacturing tolerances are typically small and do not represent a source of error when calculating total system error. However, mechanical tolerances do contribute to the coupling coefficient which impacts the overall gain of the system.

Mechanical tolerances can be divided into the following:

- Mounting mechanical tolerances: due to manufacturing tolerances,
- Lifetime mechanical tolerances: due to vibrations and thermal stress.

For the best total system accuracy, it is recommended to perform an end-of-line system calibration instead of focusing on reducing manufacturing tolerances.

6 Thermal Considerations

The current carrying conductor temperature rise is the main limiting factor when designing with serpentine slits. Any busbar design should begin with a thermal definition of the system to understand its limitations. This includes materials used, system cooling, heat sources or sinks, current on-time and current density.

Figure 8 shows a thermal image of the Evaluation Board (EVB) serpentine busbar under 300 A_{DC}. The increased temperature is found at the busbar terminal connections due to the increased resistance of the cable size and terminal bonding. However, the measured thermal rise at the busbar center where the CT452/3 current sensor would be located, is about 70°C.

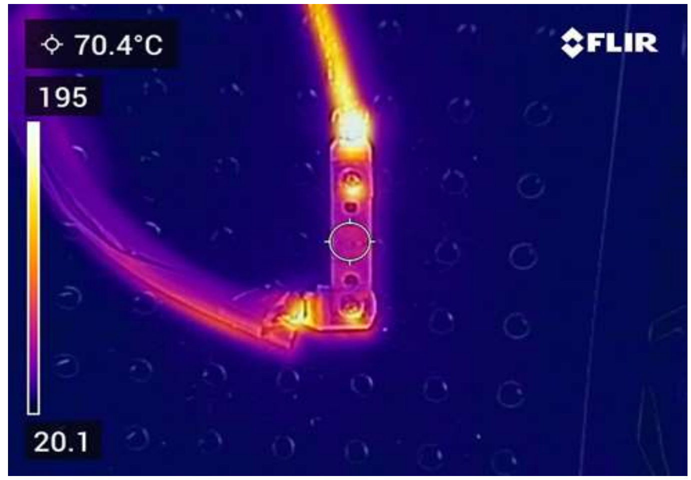

Figure 8. *The EVB thermal image at 300 ADC*

7 Conclusion

The CT452/3 is a contactless, coreless differential current sensor based on XtremeSense TMR technology from Crocus Technology. It can achieve sub 1 A resolution with a dynamic range of ±100 A to ±1000's of Amperes.

The airgap (AG) distance between the sensor and the busbar is the single most important parameter to optimize in a serpentine busbar design. Then next critical parameter is the slit width/length.

The CT452/3 offers a novel approach to current sensing with high SNR and CMFRR. For more information, contact sales@crocus-technology.com

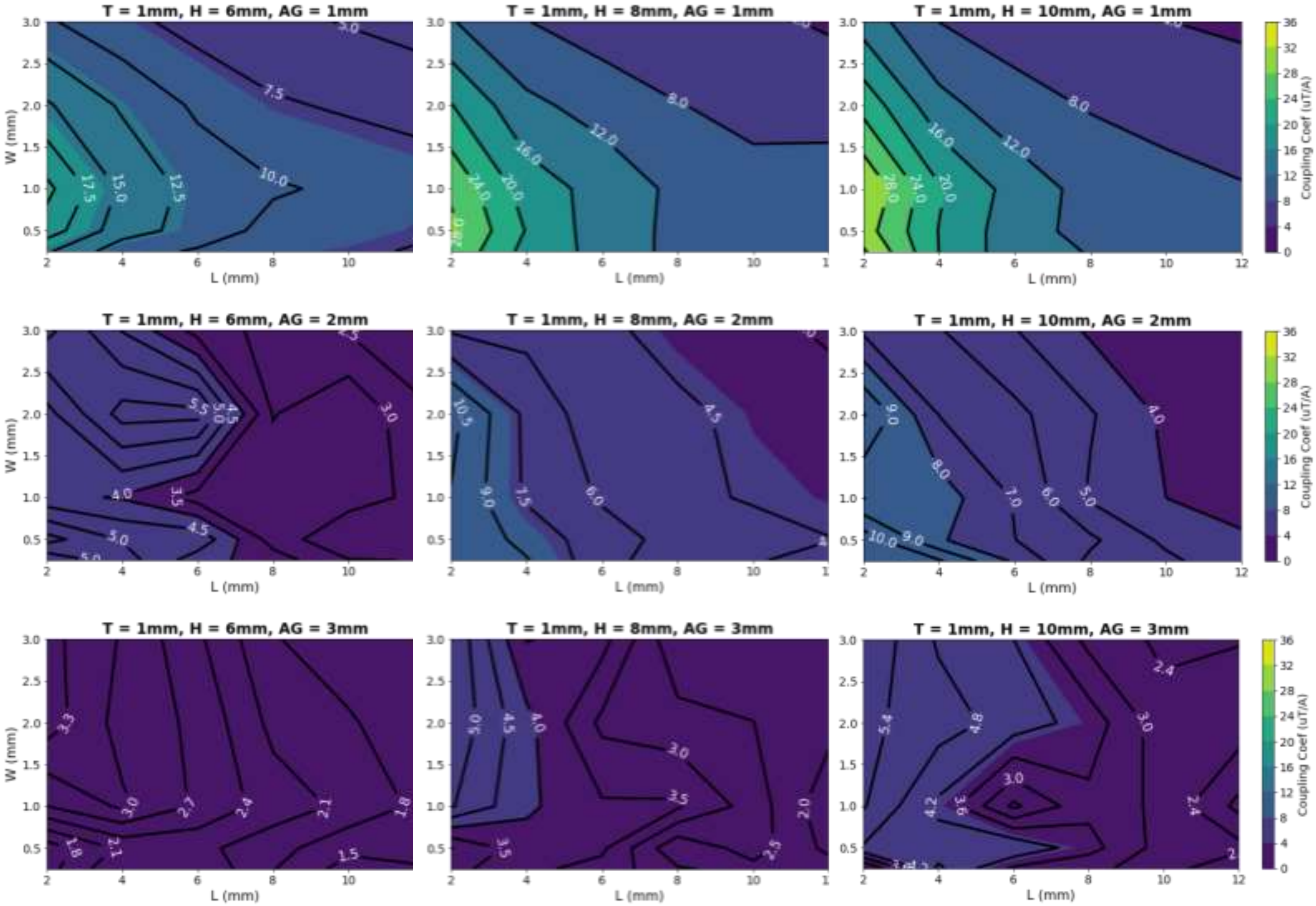

Figure 3 *Coupling Factor when for Busbar thickness of 1 mm*

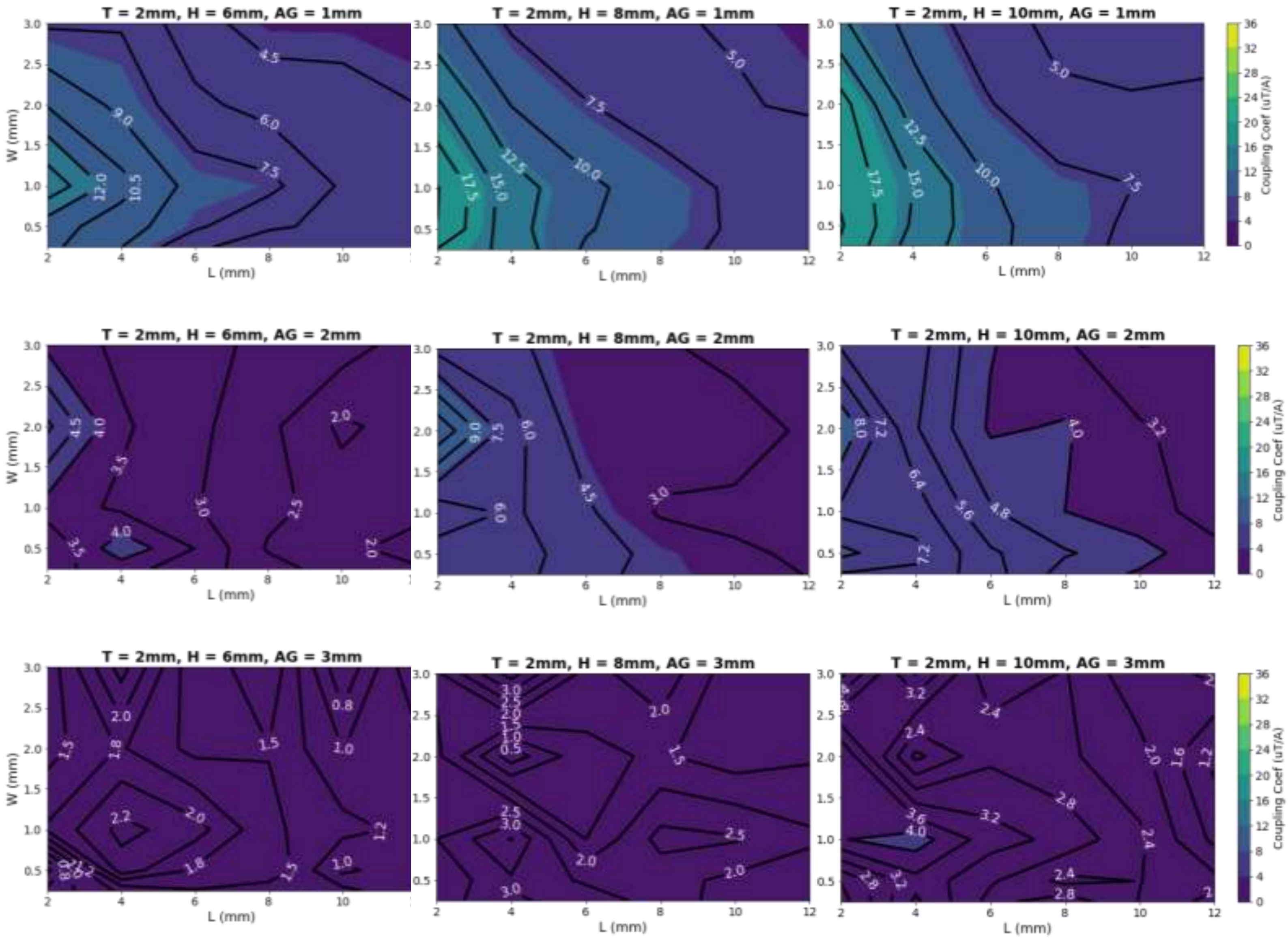

Figure 4 *Coupling Factor when for Busbar thickness of 2 mm*

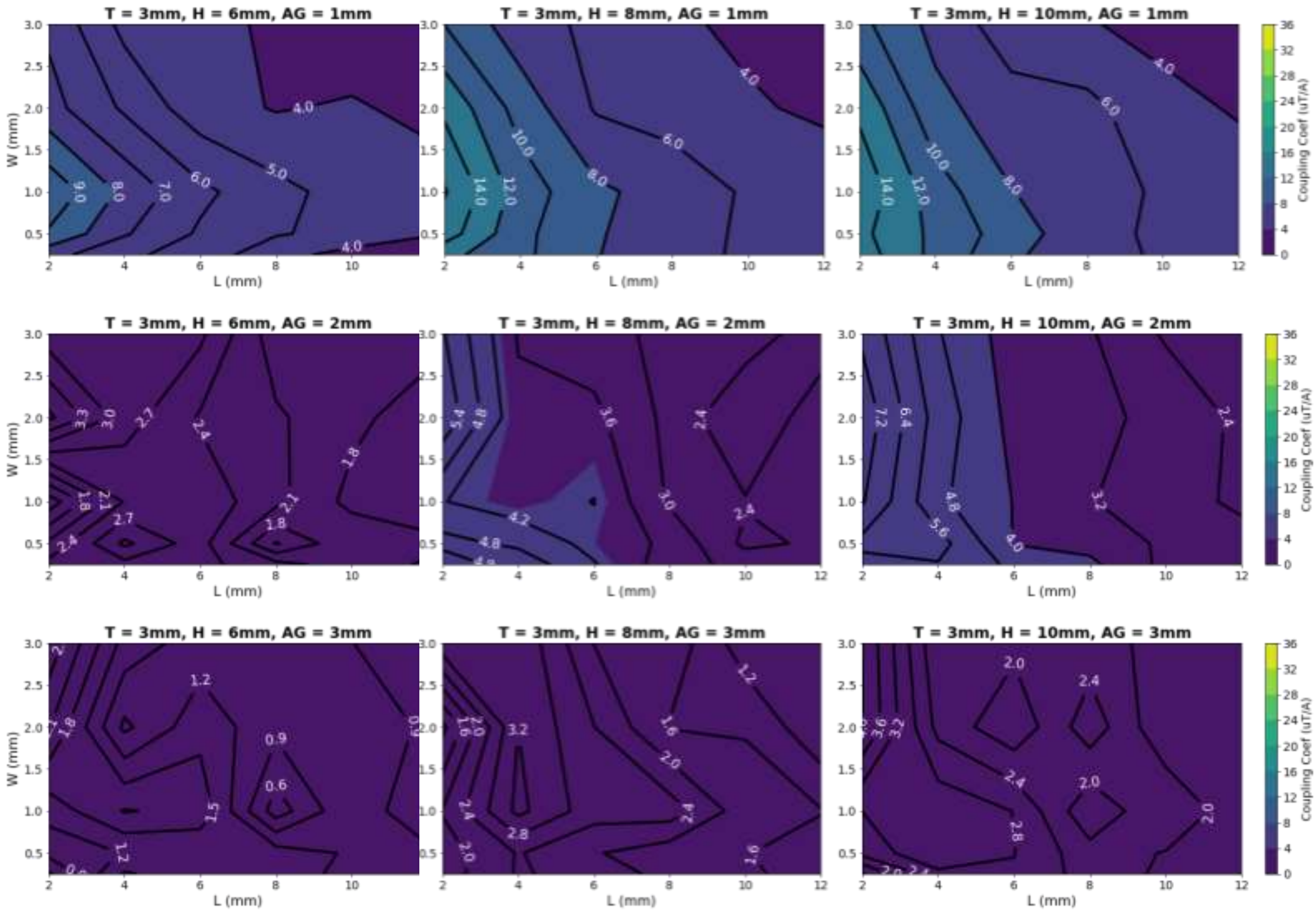

Figure 5 *Coupling Factor when for Busbar thickness of 3 mm*

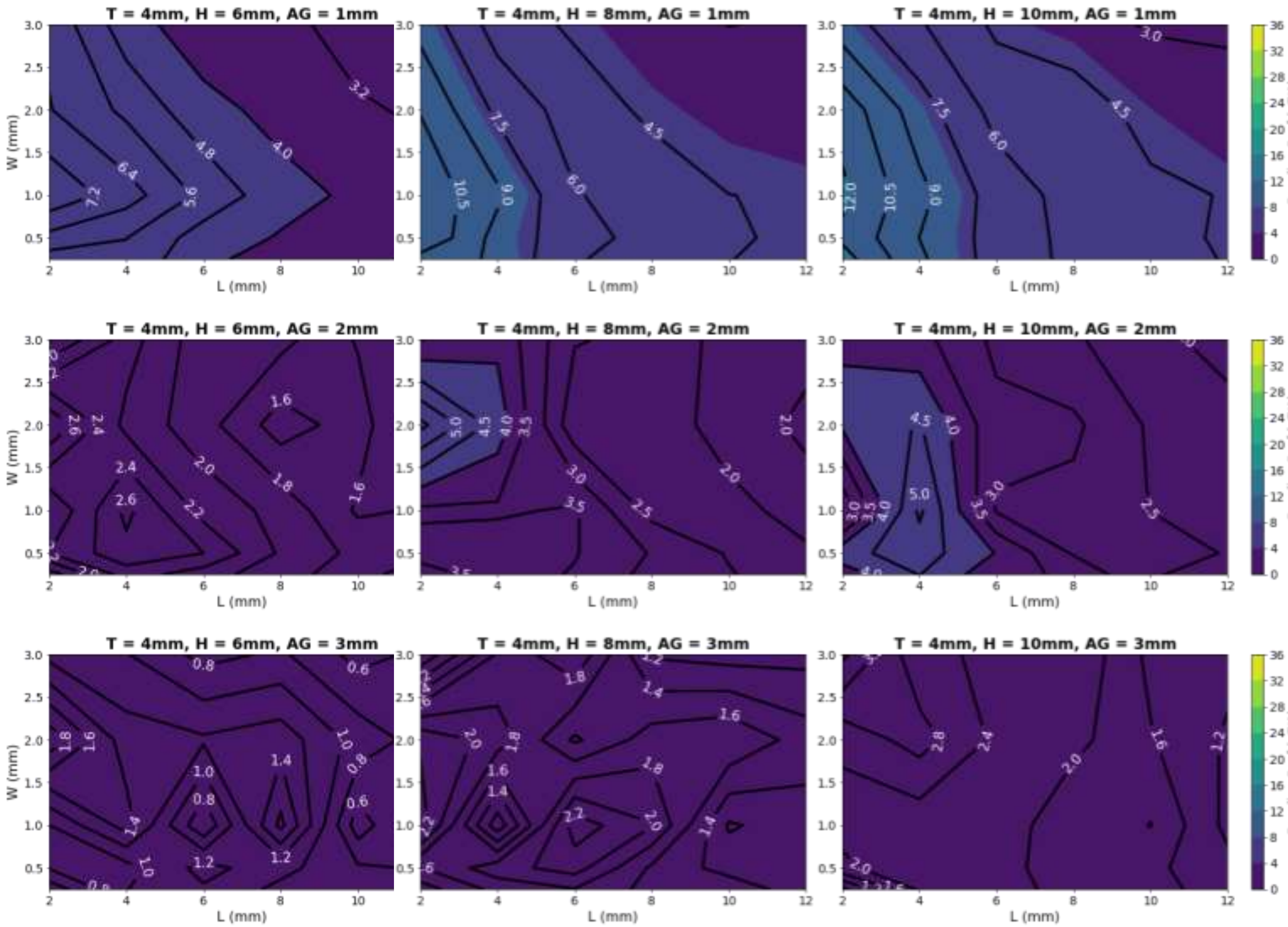

Figure 6 *Coupling Factor when for Busbar thickness of 4 mm*

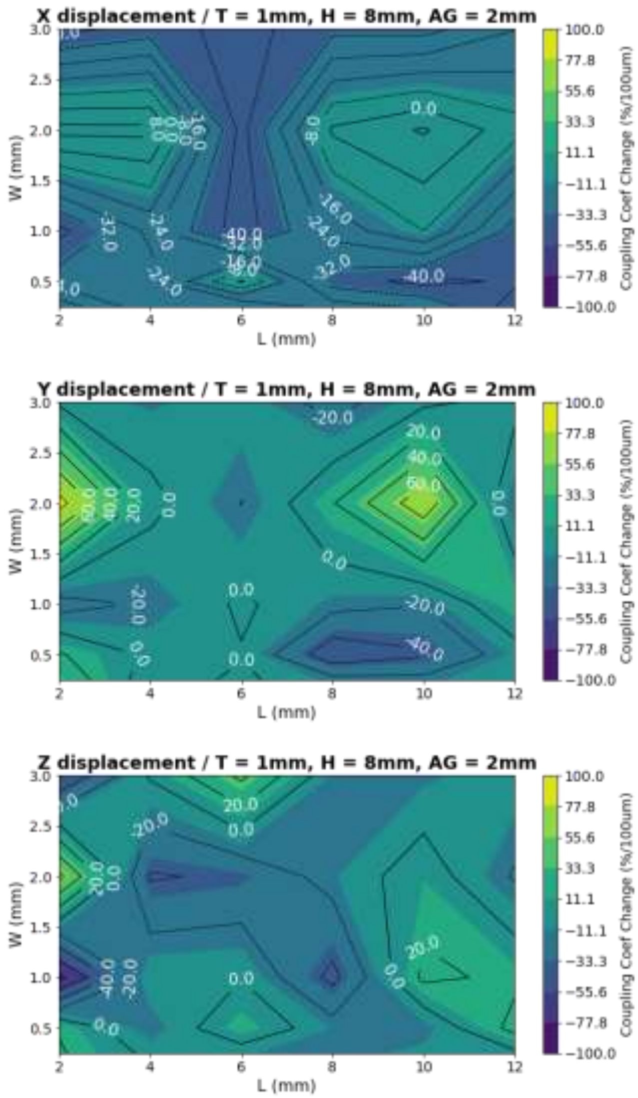

Figure 7 *Mechanical Displacement induced percentage error change*

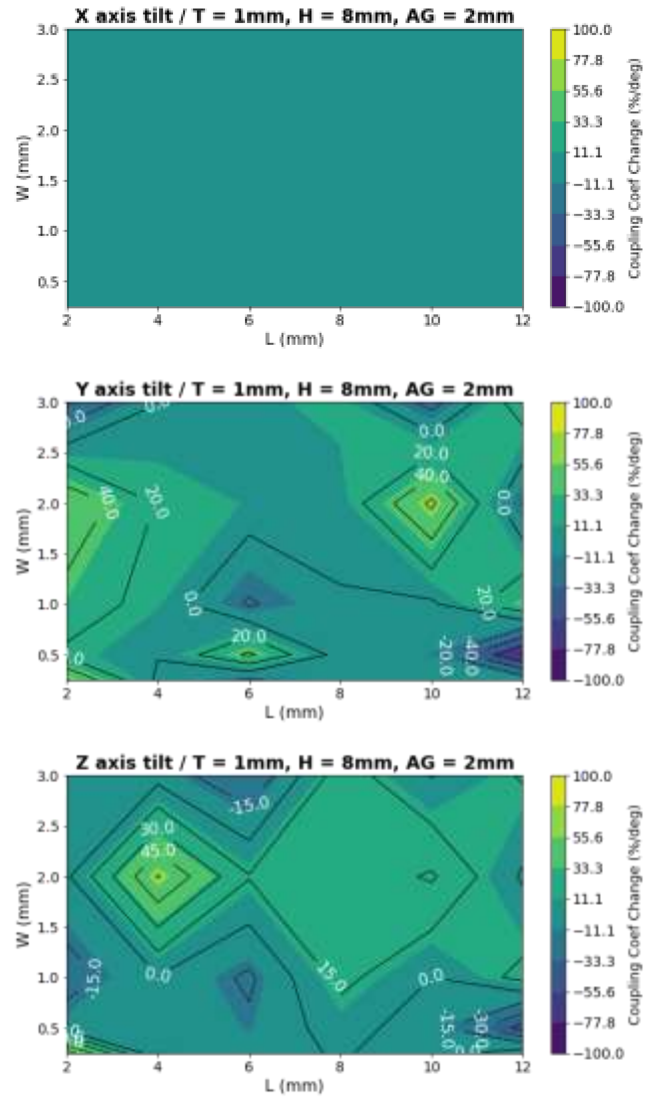

Figure 8 *Mechanical Tilt induced percentage error change*