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Calculation of the Interstrip Capacitance of the GE2/1 GEM Detector and Measurement of the Interstrip Capacitance of the GE1/1-X-S GEM Detector

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Abstract

The GE2/1 gas electron multiplier (GEM) detector is proposed for the Phase 2 upgrade of the muon detectors in the CMS experiment. As a high signal-to-noise ratio is desired in all detectors, decreasing the interstrip capacitance is of great importance in the design of the GE2/1 readout board. Analytical calculations of the interstrip capacitance for the GE2/1 are presented for different strip dimensions. Doubling the strip width, doubling the gap width, and halving the total length of the strips in the M1 and M4 modules of the GE2/1 reduces the interstrip capacitances by roughly half of the current design: from 10.4 pF to 5.1 pF in the M1 module, and from 13.6 pF to 6.3 pF in the M4 module. Comparison of the actual and calculated values of interstrip capacitance for the GE1/1-X-S detector suggests that the measured values could be roughly twice their calculated counterparts; the ratio of the average of the calculations to the average of the measurements is 1.73.

1 Introduction

Part of the Phase 2 upgrade for the CMS muon detectors includes the GE1/1 and GE2/1 detectors. One of the challenges faced with increased luminosity after the upgrade is the high muon trigger rates [1]. The GE1/1 detectors (which are currently under construction), in tandem with the current CSC ME1/1 detectors, will form the first station of muon candidate direction measurements, which increases position resolution and keeps L1 muon trigger rates under control [2]. Similarly, the GE2/1 detectors will be placed next to the CSC ME2/1 detectors, which serve as another measure of direction and further increase redundancy.

One of the challenges faced with the current design of the GE2/1 is the signal-to-noise ratio. By altering the strip dimensions on the readout (RO) board, one can decrease the interstrip capacitance, which will subsequently reduce the noise. This internal note investigates the effects of different strip parameters and reports the changes in interstrip capacitances. For comparison, physical measurements of the interstrip capacitances on the GE1/1-X-S readout board are presented along with the analytical calculations using the parameters of the GE1/1-X-S readout board.

2 Calculation of the Interstrip Capacitance of the GE2/1

The calculation of the interstrip capacitance of the strips on the readout board of the GE2/1 chamber is computed using equation (1), which is obtained through a series of conformal transformations of two co-planar strips on a dielectric substrate (see figure 1) [3]. The equation is the linear combination of the capacitance between the strips, C_a, with just air above and below with the additional capacitance between the strips due to the presence of the substrate C_s below them. This model approximates the coplanar strips on the GE1/1 and GE2/1 readout boards, and is thus employed here to obtain analytical calculations of the interstrip capacitance.

$$C = C_s + C_a = \epsilon_0 \left((\epsilon - 1) \frac{K(k')}{2K(k)} + \frac{K(k'_0)}{K(k_0)} \right) \tag{1}$$

$$k = \tanh\left(\frac{\pi g}{2h}\right) \coth\left(\frac{\pi(w+g)}{2h}\right), \qquad k' = \sqrt{1-k^2} \tag{2}$$

$$k_0 = \frac{g}{w+g}, \qquad k'_0 = \sqrt{1-k_0^2} \tag{3}$$

where $K(k)$ is the complete elliptic integral of the first kind, w is the strip width, $2g$ is the gap width, h is the thickness of the substrate (FR4 with dielectric constant $\epsilon = 4.7$), and ϵ_0 is the vacuum permittivity. All plots were produced using `MATLAB` [4], and the function `ellipke()` was used for the complete elliptic integral of the first kind.

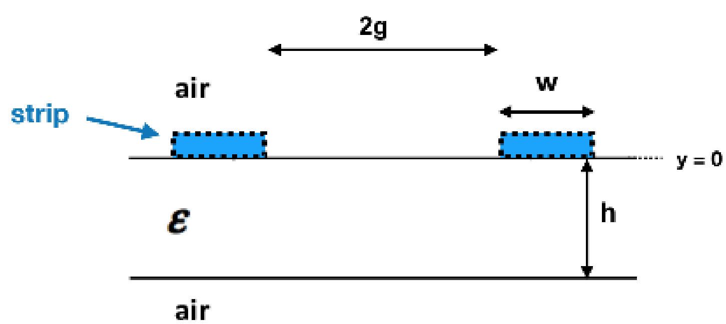

Figure 1: The strip geometry, where w is the strip width, $2g$ is the gap width, and h is the thickness of the substrate with dielectric constant ϵ.

2.1 Results

The interstrip capacitance per cm of three different configurations of the strip geometries are presented here. Note the suppressed zero on both the x and y-axes in all plots. Figure 2 is a plot of interstrip capacitance per cm of strip length vs. strip width with a fixed gap width of 0.02 cm. Interstrip capacitances per cm of strip length vs. gap width with fixed strip widths of the current configuration of the M4 and M1 modules are presented in figure 3 for module M4, and in figure 4 for module M1. Similar plots are presented in figures 5 and 6 for a fixed, doubled strip width (relative to the current strip widths of the M4 and M1 modules, respectively).

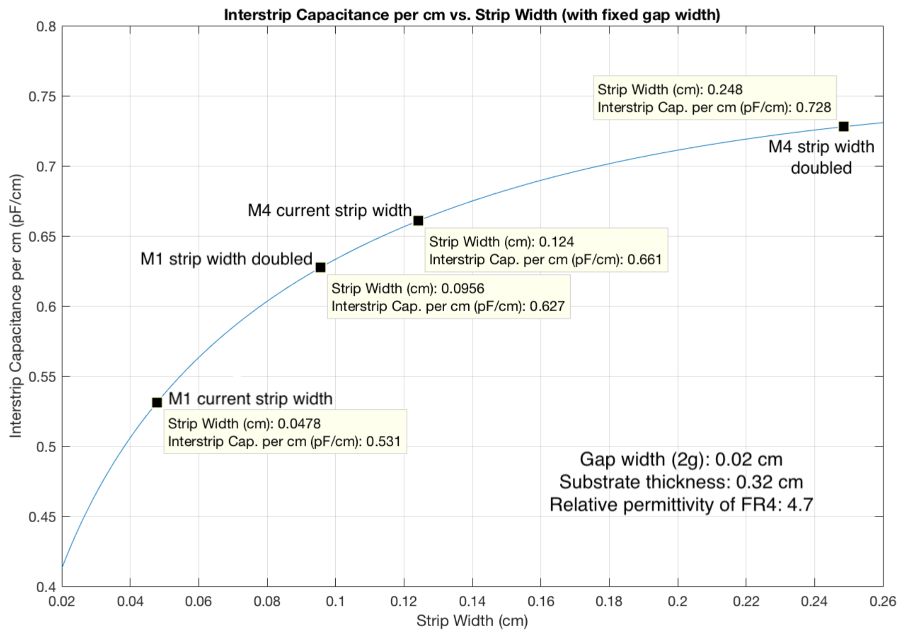

Figure 2: Interstrip capacitance per cm of strip length vs. strip width, with fixed (current) gap width.

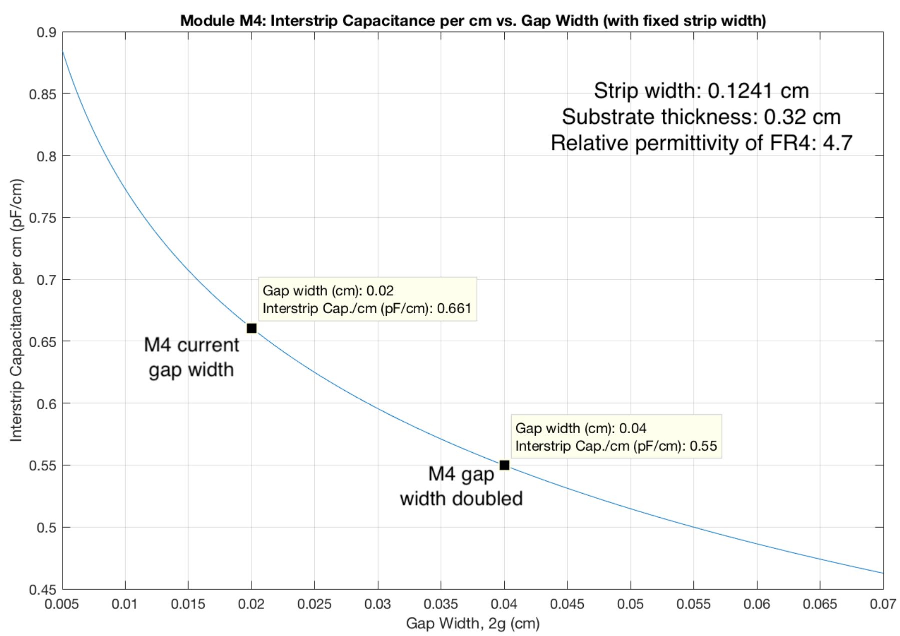

Figure 3: Interstrip capacitance per cm of strip length vs. gap width, with fixed strip width for Module M4.

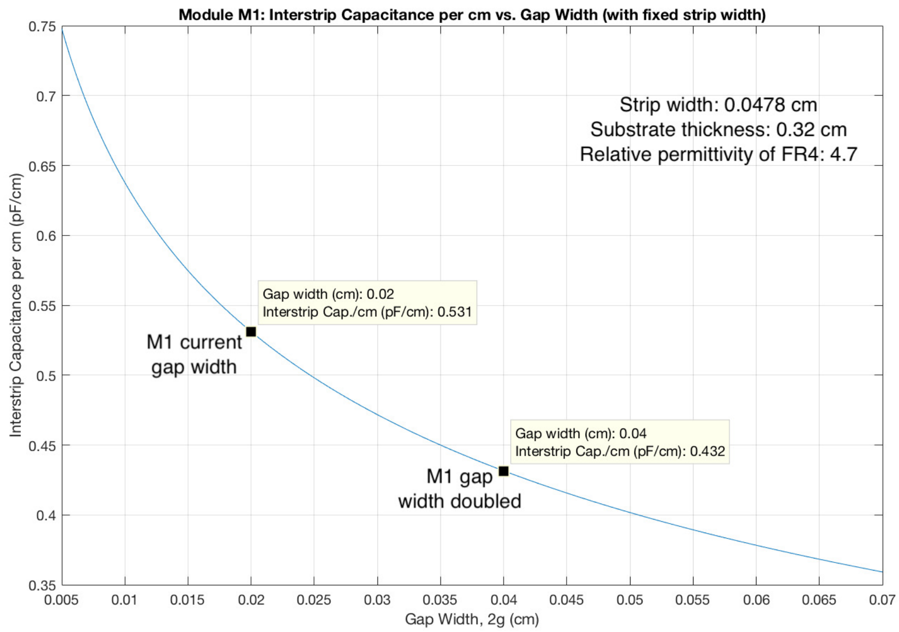

Figure 4: Interstrip capacitance per cm of strip length vs. gap width, with fixed strip width for Module M1.

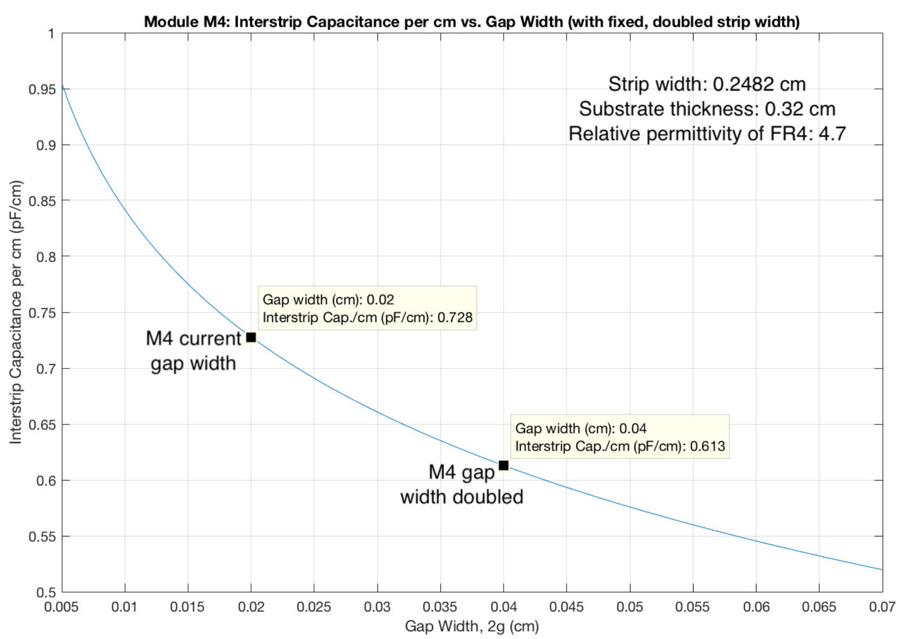

Figure 5: Interstrip capacitance per cm of strip length vs. gap width, with doubled, fixed strip width for Module M4.

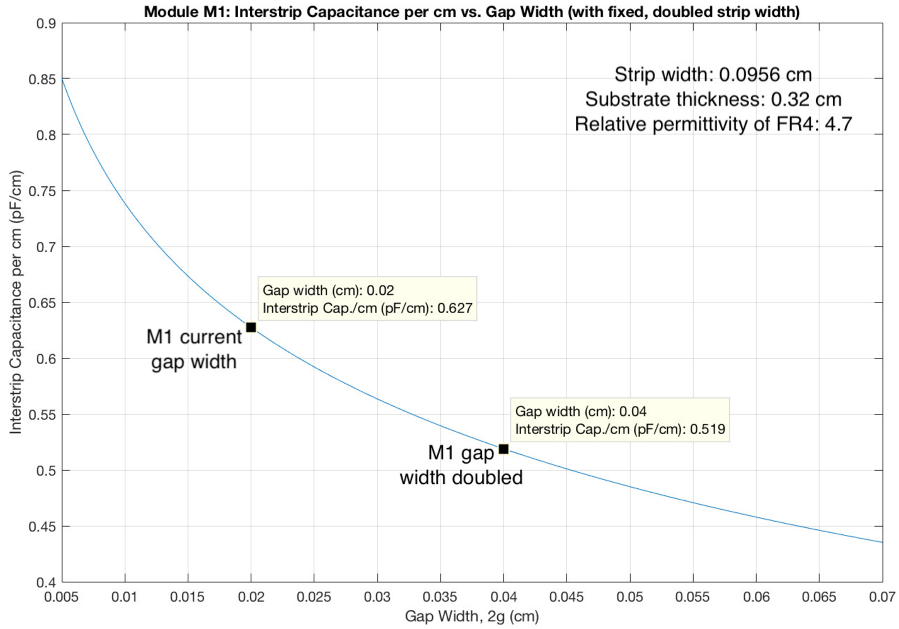

Figure 6: Interstrip capacitance per cm of strip length vs. gap width, with doubled, fixed strip width for Module M1.

Values of the interstrip capacitance per centimeter and the interstrip capacitance for the current configuration (and the previous version of the M4 module) are presented in table 1. The interstrip capacitance was calculated using maximum strip lengths $L_{M4_{old}} = 24.1$ cm, $L_{M4} = 20.6$ cm, and $L_{M1} = 19.6$ cm.

Table 1: Interstrip Capacitance of Current Configuration

Module	Capacitance/cm (pF/cm)	Capacitance (pF)
$M4_{old}$	0.661	15.9
M4	0.661	13.6
M1	0.531	10.4

Table 2 presents interstrip capacitances for three different strip configurations for the current design of the M4 and M1 modules: (1) doubling the strip width and halving the strip length while keeping the gap width constant, (2) doubling the gap width while keeping the strip length and width constant, and (3) doubling the gap width, doubling the strip width, and halving the strip length.

Doubling the strip width, doubling the gap width, and halving the total length of the strips reduces the interstrip capacitance by roughly half in both the M1 and M4 modules.

3 Interstrip Capacitance Measurements of the GE1/1-X-S Compared with Calculations

In order to compare the analytical calculations with physical measurements, the interstrip capacitances of the GE1/1-X-S readout board were calculated using equation (1) and compared with the measured interstrip capacitances. The following section details the procedure for measuring the interstrip capacitances and the method used to calculate the strip widths of the GE1/1 readout board. Section 3.2 presents the results of this comparison.

Table 2: Interstrip Capacitance of Modified Configurations

Module	Parameters	Capacitance (pF)	Ratio ($C_{new}/C_{current}$)
M4	2×width, 0.5×length (fixed current gap)	7.5	0.55
M4	2×gap (fixed current length and width)	11.3	0.83
M4	2×width, 2×gap, 0.5×length	6.3	0.46
M1	2×width, 0.5×length (fixed current gap)	6.1	0.59
M1	2×gap (fixed current length and width)	8.4	0.81
M1	2×width, 2×gap, 0.5×length	5.1	0.49

3.1 Procedure

3.1.1 Measuring the Interstrip Capacitance on the GE1/1-X-S Readout Board

In order to measure the interstrip capacitances of the GE1/1 readout board, a standard commercial capacitance meter was used. To obtain as accurate a measurement as possible, the leads of the capacitance meter were positioned at opposite ends of two adjacent strips. Before physically contacting the strips, the meter was zeroed. Three measurements were taken at five different positions within each η sector (see figure 7). The five values of each sector were then averaged to produce the values listed in table 4.

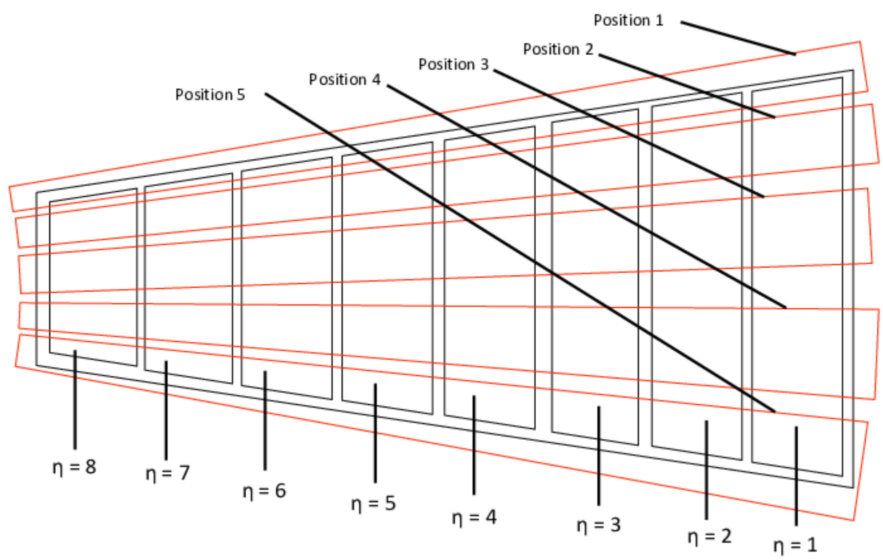

Figure 7: Location of the positions where measurements were taken in each eta sector on the GE1/1-X-S RO.

3.1.2 Calculating the Strip Widths of the GE1/1-X-S Readout Board

The strip widths on the GE1/1-X-S readout board were calculated by measuring the width of the midpoint of the active region of the RO in each η sector and then using this measurement in the following expression:

$$w = \frac{\text{measured width} - \left[(383\,\text{strip gaps})\,(0.02\,\text{cm})\right]}{384 \text{ strips}} \tag{4}$$

where w is the strip width. Strip widths are listed in table 3.

Table 3: Calculated Strip Widths for the GE1/1-X-S RO Board in All Eta Sectors

Eta Sector	1	2	3	4	5	6	7	8
Strip Widths (cm)	0.0933	0.0769	0.0703	0.0634	0.0567	0.0527	0.0470	0.0426

3.2 Results

Comparison of the measured and calculated values of the interstrip capacitance reveals that the calculated values of capacitance are on average 58% smaller than the measured value (see table 4). This discrepancy can be attributed to the simplified model used to calculate the interstrip capacitances as it only considers two strips, whereas on the readout board there are 384 strips per eta sector. Therefore, it is important to note that values calculated for the GE2/1 interstrip capacitance presented in tables 1 and 2 could potentially be roughly twice their calculated value.

Table 4: Measured and Calculated Interstrip Capacitances per cm of the GE1/1-X-S RO Board in All Eta Sectors

Eta Sector	1	2	3	4	5	6	7	8
Calc. Cap./cm (pF/cm)	0.624	0.598	0.585	0.571	0.555	0.545	0.529	0.515
Avg. Meas. (pF/cm)	1.02	0.946	0.942	1.01	1.04	1.00	0.909	0.952
Meas. Error (pF/cm)	±0.08	±0.084	±0.086	±0.10	±0.16	±0.11	±0.128	±0.187
Ratio (Calc./Avg. Meas.)	0.61	0.63	0.62	0.57	0.54	0.54	0.58	0.54

4 Summary and Conclusion

This note presented the analytical calculations for different strip geometries of the GE2/1 RO board. In order to halve the interstrip capacitance in the M4 and M1 models, the strip width and strip gap should be doubled, and the length of the strip should be halved. Analytical calculations were compared to the actual interstrip capacitance of the GE1/1-X-S, which revealed that the calculated values were roughly half their measured value. This should be considered when implementing different strip geometries, and to confirm this difference the interstrip capacitance of the GE2/1 should be measured.

References

[1] CMS Collaboration, "The Phase-2 Upgrade of the CMS Muon Detectors Technical Design Report," Technical Report CERN-LHCC-2017-012, CMS-TDR-016, CERN, 2017.

[2] CMS Collaboration, "CMS Technical Design Report for the Muon Endcap GEM Upgrade," Technical Report CERN-LHCC-2015-012, CMS-TDR-013, CERN, 2015.

[3] S. Gevorgian and H. Berg, "Line Capacitance and Impedance of Coplanar-strip Waveguides on Substrates with Multiple Dielectric Layers," *31st European Microwave Conference, IEEE (2001)*, doi:10.1109/EUMA.2001.339161.

[4] Mathworks, Inc., MATLAB, version R2018a.