CAPACITIVE SENSING - MODELLING APPLICATION NOTE

Product Family: **EM4152**

Part Number: EM4152V001WS6U
Keywords: Capacitive sensor

1. ABSTRACT

The device EM4152V001WS6U aims at being connected to a capacitive sensing element (CSENSE) between the pads CAP+ and CAP- as shown in the figure 1 below.

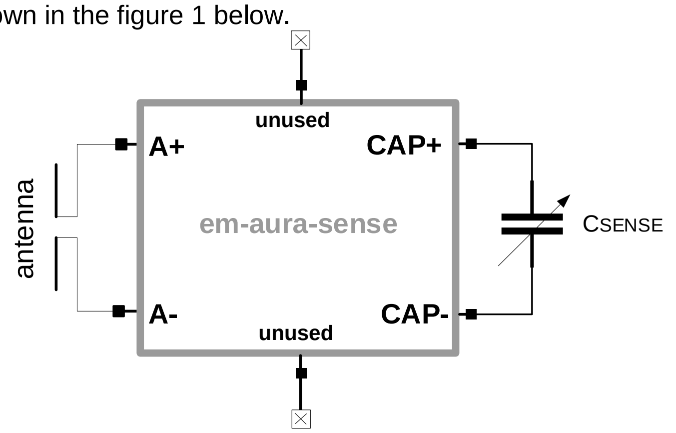

Fig.1: Connecting em|aura-sense to a capacitive sensing element

The capacitance value can be converted to digital information as described in the em|aura-sense datasheet.

Depending on the capacitor dimensions, the capacitance may be sensitive to the presence of a conductive element close to the capacitor electrodes.

The design of the capacitive sensor element may also affect the capacitance to digital conversion due to inadequate parasitic elements.

The scope of this document is twofold:

- to describe recommendations on capacitive sensing element modelling such that the capacitive conversion is not disturbed by these parasitic components
- to describe generic modelling recommendations to allow a sensitivity of the capacitor CSENSE with regards to proximity of conductive elements close the capacitor

2. THE CAPACITOR PARASITICS

2.1 DESCRIPTION OF TYPICAL PARASITICS

Typical parasitic components around the Sensing capacitor are described in the figure 2 below:

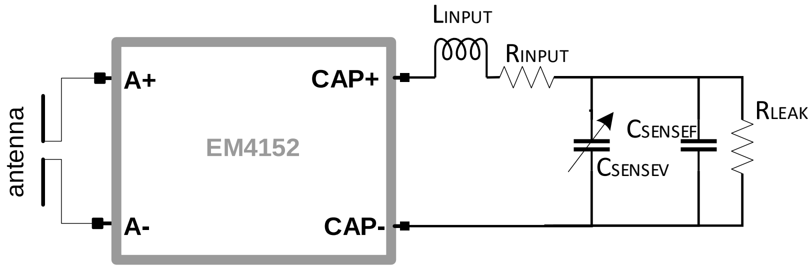

Fig. 2: typical application diagram for em|aura-sense with parasitics on sensing element

CSENSE can indeed be splitted in 2 components:

- CSENSEF: When there is no conductive material in close to the capacitor electrodes the capacitor value CSENSE reaches it minimum value. This value is the electrostatic capacitor between the 2 formed electrodes
- CSENSEV: When approaching a conductive material close to the capacitor electrodes the capacitor value increases due to the formation of additional capacitance between the 2 electrodes and the conductive material (When no external conductive material is present CSENSEV=0

LINPUT, RINPUT: are respectively the parasitic inductance and resistance of the wire connection from the CAP+/CAP- pads to the center of the capacitor electrodes

RLEAK: Depending on the insulating material used to form the sensing capacitor, current will leak between the 2 capacitor electrodes

2.2 LIMITS OF THE CAPACITOR PARASITICS

In order to ensure a correct behavior of the capacitive sensing interface, the parasitic must remain in the boundaries as described below:

Model parameter	Min	Max	Unit
LINPUT	0	1000	nH
RINPUT	0	100	kOhm
CSENSE+CSENSEF	0	17	pF
RLEAK	400	12000	MOhm

Table 1: limit of the parasitics of capacitive sensing element

3. CAPACITIVE SENSING MODELLING RECOMMENDATIONS

3.1 RECOMMENDATIONS LINKED TO THE PARASITICS

Under the assumption that the connection (LINPUT/RINPUT) is realized thanks to 1 metal line and that its width is one order of magnitude lower than its length, the connection between CAP+/CAP- and the capacitor connection cannot be longer than 50cm.

Other dimension constraints will depend on the materials used to realize the material (insulation and conductive materials). For instance,

- RINPUT can be calculated thanks to the conductivity ρCONNECTION of the connection material used:
  RINPUT= ρCONNECTION * L / S
  LACCESS being the length of the connection and S the cross-section surface of the metal connection:
  S=HELECTRODE X WACCESS
  HELECTRODE and WACCESS being respectively the height and the width of the access connection

- RLEAK can be calculated thanks to the insulating conductivity of the material between the capacitor electrodes (ρINSULATOR):
  RLEAK= ρINSULATOR * LINSULATOR / SELECTRODE
  The dimensions are placed differently as shown in the figure below:

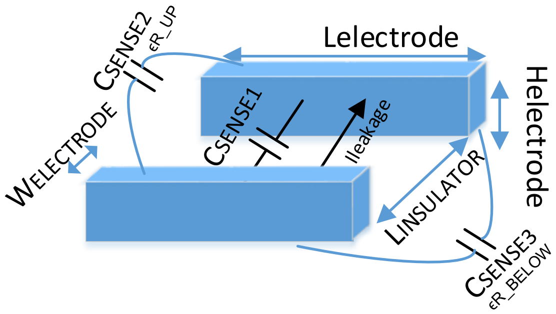

Fig.3: Capacitance value and leakage formed by 2 parallel electrodes

SELECTRODE = LELECTRODE * HELECTRODE being the overlapping surface of the 2 capacitor electrodes

- The fixed part of the capacitor (not dependent on the environment) CSENSEF can be calculated thanks to the relative permittivity of the insulating material (εINSULATOR):

$$\mathrm{CSENSEF} = \epsilon 0 * \left[\underbrace{\frac{\epsilon R_{BELOW} + \epsilon R_{UP}}{\pi} . \ln\left(1 + 2 * \frac{\mathrm{WELECTRODE}}{\mathrm{LINSULATOR}}\right)}_{\text{CSENSE2+CSENSE3}} + \underbrace{\epsilon \mathrm{INTERELECTRODE} * \mathrm{HELECTRODE}/\mathrm{LINSULATOR}}_{\text{CSENSE1}} \right] * \mathrm{LELECTRODE}$$

CSENSEF being the sum of fringe capacitors (CSENSE2 and CSENSE3) and Plate capacitor (CSENSE1)
LELECTRODE being the length of the electrodes in regard where the dimensions (LELECTRODE, HELECTRODE and LINSULATOR) are referring to the previous figure 3.

- The inductance of the connection LINPUT can be calculated thanks to Groover self inductance equation:

$$LINPUT = \frac{\mu * \mathrm{LACCESS}}{2 * \pi} * (\ln\left(\frac{2 * LACCESS}{WLECTRODE + HELECTRODE}\right) + \frac{1}{2} + \frac{WLECTRODE + HELECTRODE}{4 * LACCES})$$

Where μ is the magnetic permeability of the material surrounding the connections (as rough estimation, 1nH per 1mm of connection)

Hence, the parasitics can be calculated thanks to the dimensions and process parameters as shown in the example excel object embedded in table 2 below:

Electrical parameters of the material used

Process parameter	Value	Unit
µ0	1.26E-06	H.m-1
µR	1	
ϵ0	8.85E-12	F/m
ϵR_BELOW	3	
ϵR_UP	3	
ϵINTERELECTRODE	3	
ρINSULATOR	5.40E+05	Ohm.m
ρCONNECTION	2.65E-08	Ohm.m

Design parameters

Dimensions	Value	Unit
HELECTRODE	9.0E-06	m
LINSULATOR	1.0E-03	m
LELECTRODE	4.1E-02	m
WELECTRODE	1.0E-03	m
LACCESS	1.1E-02	m
WACCESS	1.0E-03	m

Parasitic	culated va	Unit	Min	Max	PASS/FAIL
LINPUT	15.9	nH	0	1000	PASS
RINPUT	6.48E-02	Ohm	0	100000	PASS
CSENSE	0.775	pF	0	17	PASS
RLEAK	1.46E+03	Mohm	400	10000	PASS

Table 2: example of parasitics and capacitance value for the sensing element – no conductive element

From the previous calculation in our considered case: $C_{SENSEF}=0.775pF$

3.2 VARIATION OF THE CAPACITANCE DUE TO EXTERNAL CONDUCTIVE MATERIAL

When approaching a conductive material close the electrodes, the electrostatic configuration is changed. Additional capacitances appears as shown in the capacitor network in figure 3a and 3b below:

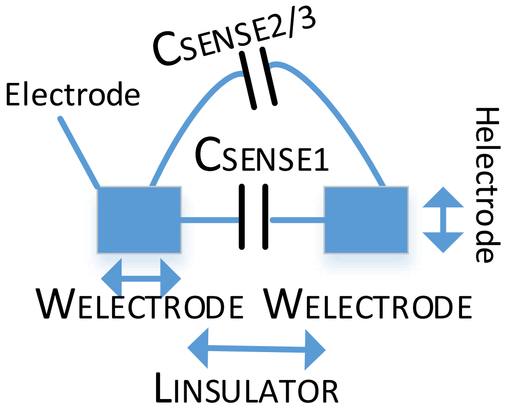

Fig. 3a: Without conductive material perturbation

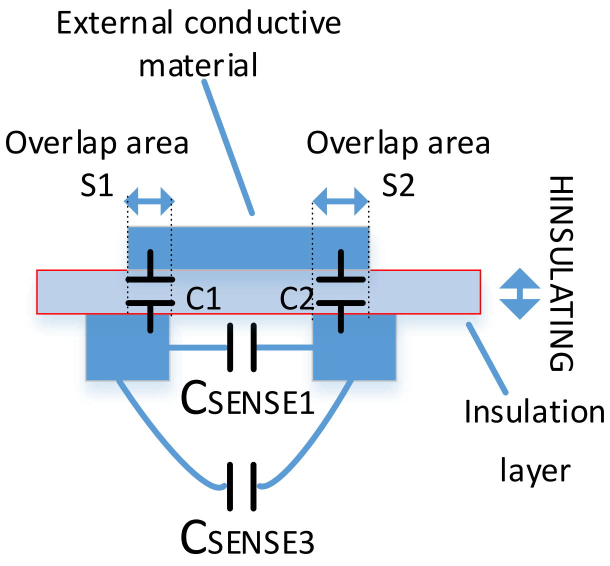

Fig. 3b: Conductive material placed close to the electrodes

When no conductive material is present close to the capacitor electrodes (fig. 3.a), the capacitor between the 2 electrodes can be calculated thanks to equation described in section 3.1. The capacitor value depends on both process and physical parameters.
When a conductive material is present close to the electrodes (fig. 3b), the plate capacitors will appear between electrodes and conductive material (represented by C1 and C2). Under the assumption that the conductive material is touching the insulating layer, the 2 plate capacitances can be calculated thanks to the following equations:

$$C1/2 = \epsilon 0 \ * \left[\epsilon \mathrm{INTERELECTRODE} * \frac{S1/2}{\mathrm{H_{INSULATING}}}\right]$$

CSENSE1 and CSENSE3 being calculated in the same way as in section 3.1:

$$\mathrm{CSENSE1} = \epsilon 0 \ * \left[\epsilon \mathrm{INTERELECTRODE} * {}^{\mathrm{HELECTRODE}}/_{\mathrm{LINSULATOR}}\right] * \mathrm{LELECTRODE}$$

$$\mathrm{CSENSE3} = \epsilon 0 \ * \left[\frac{\epsilon \mathrm{R_{BELOW}}}{\pi} . \ln\left(1 + 2 * \frac{\mathrm{WELECTRODE}}{\mathrm{LINSULATOR}}\right)\right] * \mathrm{LELECTRODE}$$

An example of calculation of capacitance increase due to a presence of a conductive layer with surface of 7.5E-7m2 on each electrodes see excel embedded in table 3 below:

Electrical parameters of the material used

Process parameter	Value	Unit
ϵ_0	8.85E-12	F/m
ϵR_BELOW	3	
ϵR_UP	3	
ϵINTERELECTRODE	3	
$\rho_{INSULATOR}$	5.40E+05	Ohm.m
$\rho_{CONNECTION}$	2.65E-08	Ohm.m

Design parameters

Dimensions	Value	Unit
HELECTRODE	9.0E-06	m
LINSULATOR	1.0E-03	m
LELECTRODE	4.1E-02	m
WELECTRODE	1.0E-03	m
LACCESS	1.1E-02	m
HINSULATing	1.2E-05	m
WACCESS	1.0E-03	m
S1	7.5E-07	m2
S2	7.5E-07	m2

Parasitic	Calculated valu	Unit	Min	Max	PASS/FAIL
CSENSE	1.232	pF	0	17	PASS
C1	1.66E+00	pF			
C2	1.66E+00	pF			
CSENSE3	3.83E-01	pF			

Table 3: example of parasitics and capacitance value for the sensing element – no conductive element

From our calculation, CSENSEF+CSENSEV=1.23pF

3.3 EVALUATION OF THE SENSITIVITY

The example being based on the capacitive sensor from section 3.1, the difference in capacitance between the situation with and without conductive material is CSENSEV=0.45pF.
Using the em|aura-sense to detect the variation of this capacitance value will then give a code variation:
450 [fF]/160 [fF/LSB] =3LSB