Capacitive Protection System for Robot dedicated to the Safety of Humans

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Outline

I. Towards a model (5 slides)
- Capacitive coupling (1 slide)
- Coefficients of capacitance and induction (1 slide)
- Implementation, Modelisation and Validation (3 slides)

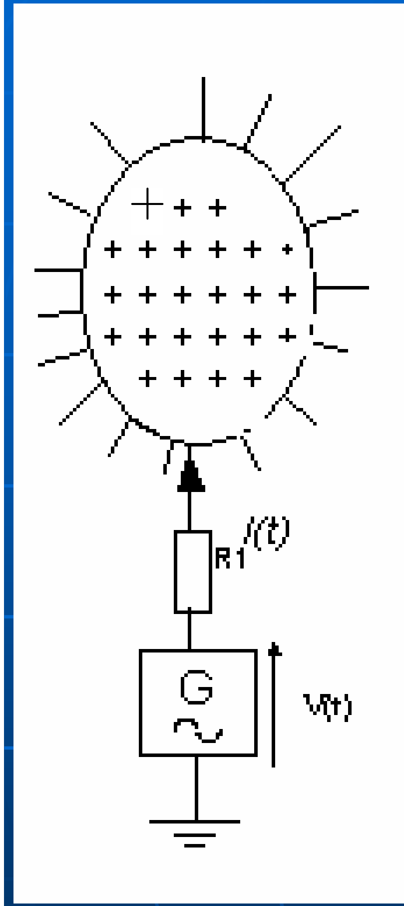
II. Detection and discrimination set-up (2 slides)
- Detection of an intruder (1 slide)
- Discrimination Human/Object and evaluation of the distance intruder/active sensor (1 slide)

III. Practical implementation and Precaution (2 slides)

IV. Conclusion

INPI (french National Institute of Intellectual Protection) under the number : 0602599 at the date 27/03/06

I. Towards a model : CAPACITIVE COUPLING

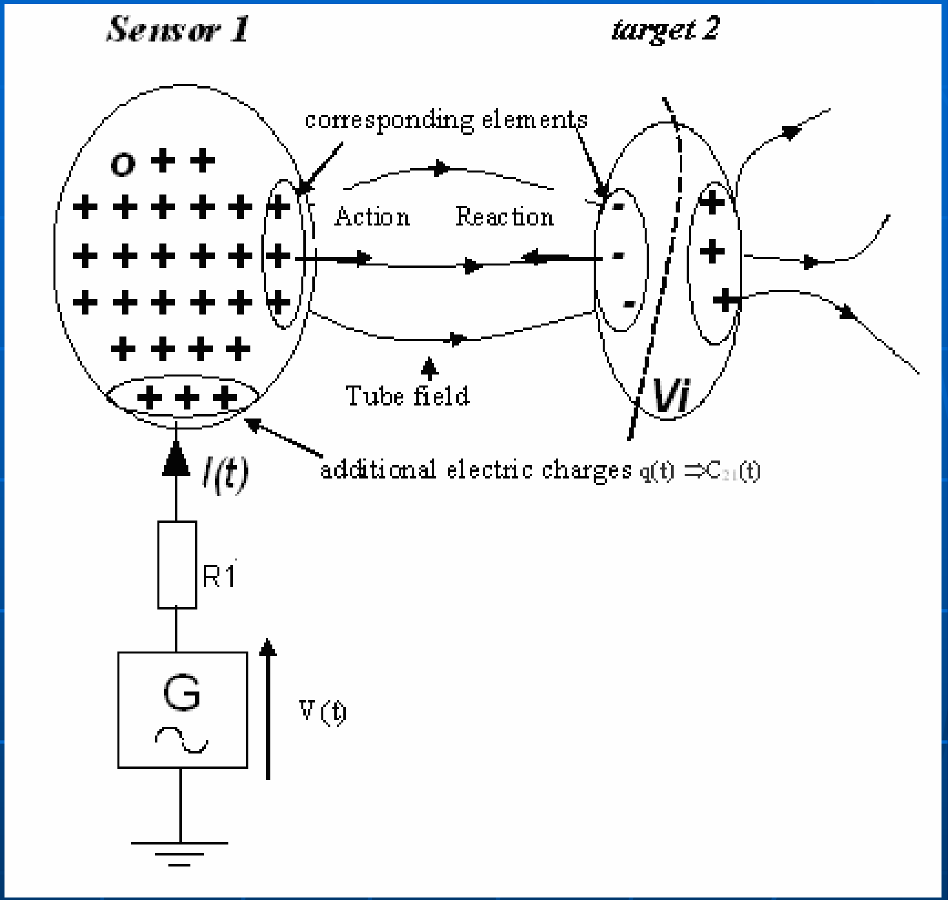


$V(t)=V_0 \sin(2\pi f t)$

C_{S0} : coefficient of capacitance of a sensor without target.

$$C_{S0} = \frac{Q(t)}{V(t)}$$

C_{11} : coefficient of capacitance of a 'sensor 1' in front of a target.

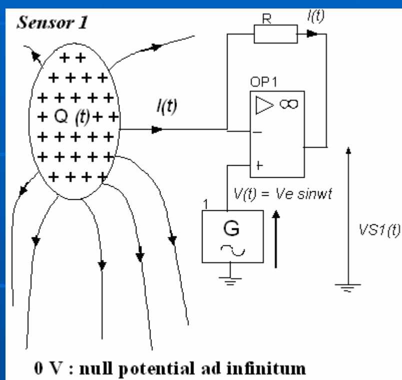


$$C_{11}(t) = \frac{Q(t)+q(t)}{V(t)} = C_{1S}(.,.,.) + C_{21}(t) \qquad C_{1S}(.,.,.) = C_{11}(t) - C_{21}(t)$$

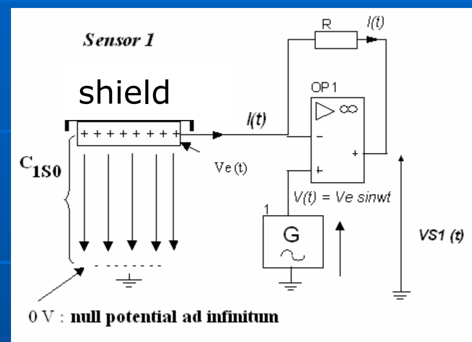
C_{1S} is the coefficient of capacitance of the sensor

$C_{21} = C_{12}$ is the coefficient of induction of a target on the 'sensor 1'.

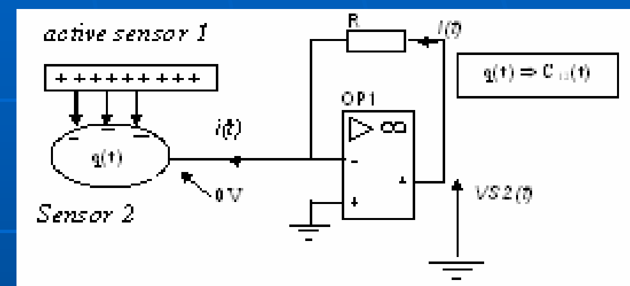
I. Towards a model :
COEFFICIENTS OF CAPACITANCE AND INDUCTION
How to measure ?



Capacitance C_{11}

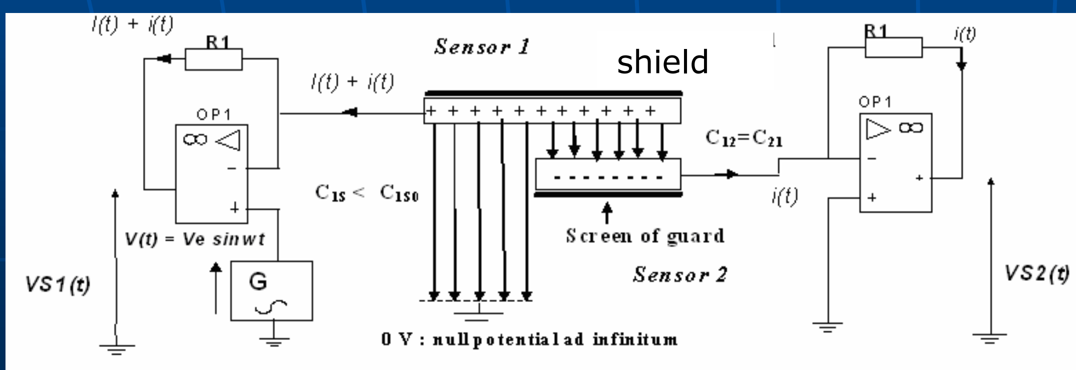


Capacitance C_{12}



Model (1) $V_{S1} = V_e\sqrt{1+[R\omega C_{11}]^2} = V_e\sqrt{1+(R\omega)^2[C_{1S}(.,.,.)+C_{21}]^2}$

Model (2) $V_{S2} = V_e\, R\, \omega\, C_{12}$



$$C_{11} = C_{1S}(.,.,.) + C_{21} = \frac{1}{V_e R\omega}\sqrt{V_{S1}^2 - V_e^2}$$

$$C_{12} = C_{21} = \frac{1}{V_e R\omega} V_{S2}$$

I. Towards a model :
MODELISATION, IMPLEMENTATION and VALIDATION (1/3)

Theorical model (3) : from eq(1) and eq(2)

Eq(1) $$C_{11} = C_{1S}(.,.,.) + C_{21} = \frac{1}{V_e R\omega}\sqrt{V_{S1}^2 - V_e^2}$$

Eq(2) $$C_{12} = C_{21} = \frac{1}{V_e R\omega} V_{S2}$$

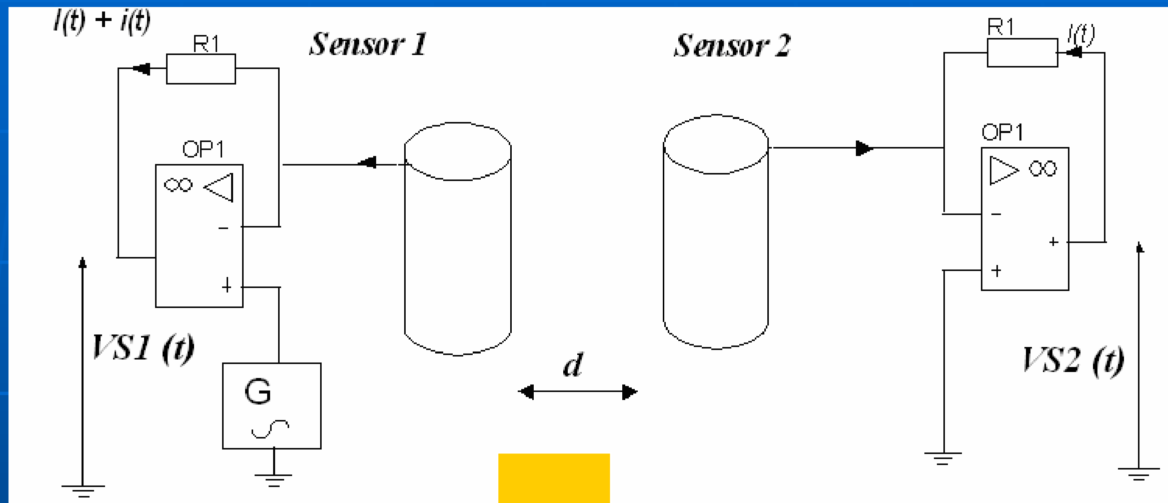
Mod(3) $$C_{1S}(.,.,)_{exp} = C_{11} - C_{21} = \frac{1}{V_e R\omega}\left(\sqrt{V_{S1}^2 - V_e^2} - V_{S2}\right)$$

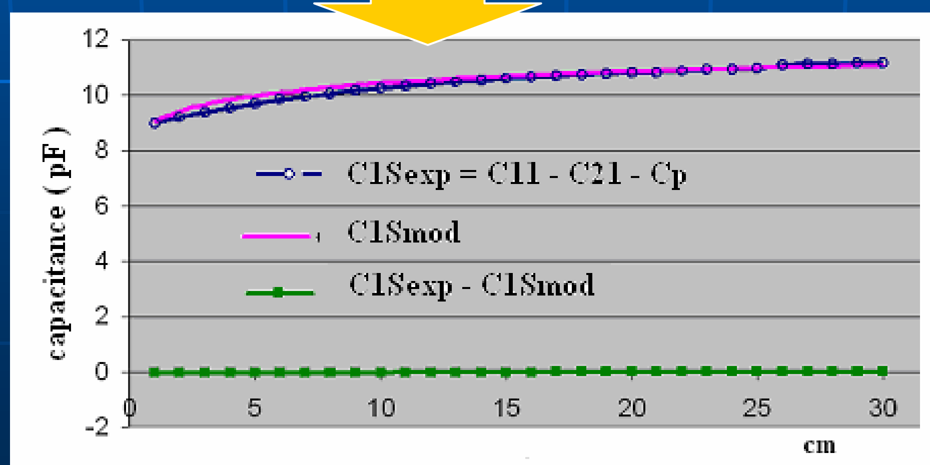
Reference model (4) : experimentally established

Mod(4) $$C_{1S}(.,.,.)_{model} = C_{1S0}\left[1 - \frac{C_{21}^{\alpha}}{C_{1S0} + C_{21}}\right] \text{with } \alpha = \frac{C_{1S0} + \beta C_{21}}{C_{1S0}}$$

where β is an empirical variable of adjustment.
available 3mm < d < 500mm

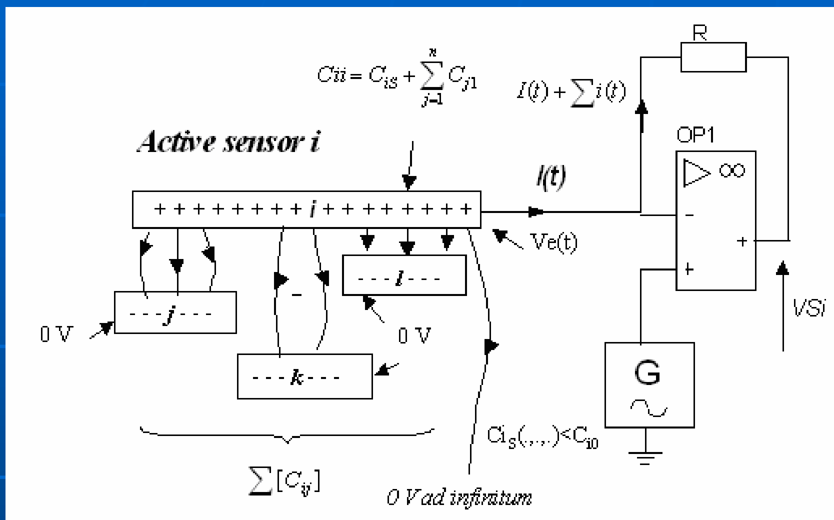
I. Towards a model :
MODELISATION, IMPLEMENTATION and VALIDATION (2/3)



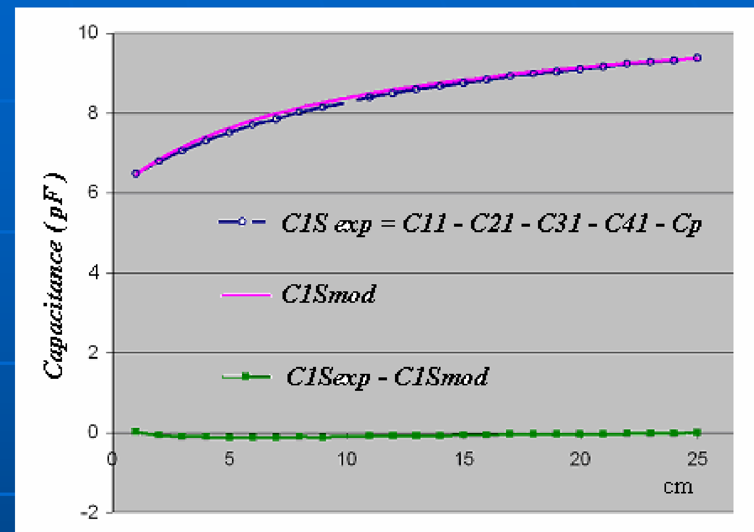


Model
Validation
$\beta = 1$

I. Towards a model :
MODELISATION, IMPLEMENTATION and VALIDATION (3/3)
Generalization: one active 'sensor i' and n-1 inactive sensors



Translation of the coupling for n passive sensors



Validation of the models $\beta = 1$

Reference model (5) :

$$C_{iS}(.,.,.)_{ref} = C_{iS0}\left[1-\frac{\sum_{j=1,\, i\neq j}^{n} C_{ji}^{\alpha}}{C_{iS0}+\sum_{j=1,\, i\neq j}^{n} C_{ji}}\right],\quad \alpha=\frac{C_{iS0}+\beta\sum_{j=1,\, i\neq j}^{n} C_{ji}}{C_{iS0}}$$

Experimental model (6) :

$$C_{is}(.,.,)_{exp} = C_{ii} - \sum_{j=1, i\neq j}^{n} C_{ji} = \frac{1}{V_e R\omega}\left(\sqrt{V_{Si}^2 - V_e^2} - \sum_{j=1, i\neq j}^{n} V_{Sj}\right)$$

Outline

I. Towards a model (5 slides)
- Capacitive coupling
- Coefficients of capacitance and induction
- Modelisation, Implementation and Validation

II. Detection and discrimination set-up (2 slides)
- Detection of an intruder (1 slide)
- Discrimination Human/Object and evaluation of the distance intruder/active sensor (1 slide)

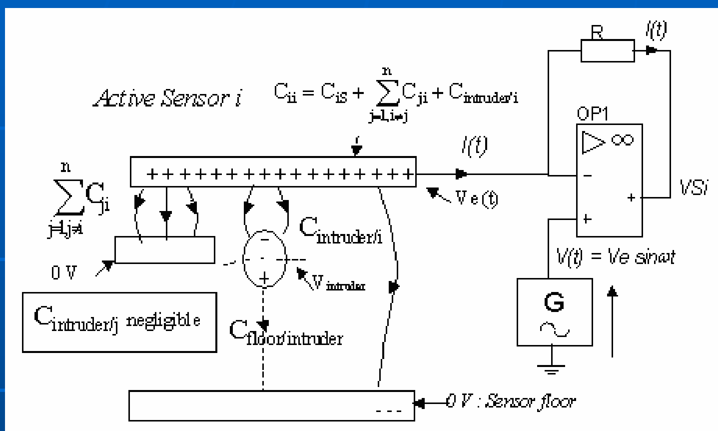
III. Practical implementation and Precaution (2 slides)

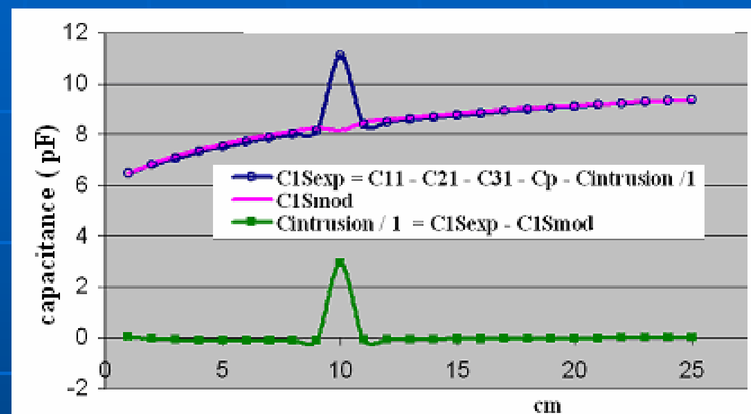
IV. Conclusion

INPI (National institute of intellectual protection) under the number : 0602599 at the date 27/03/06

II. Detection and Discrimination Set-up:
DETECTION OF AN INTRUDER AND VALIDATION

A. The intruder is **not in contact** with the floor (far enough), this latter behaves like a ‘sensor j’ at a null potential





By measuring the potential at the output of the circuit

Reference model

$$V_{Si} = V_e\sqrt{1+(R\omega)^2[C_{iS} + \sum_{j=1,i\neq j}^{n} C_{ji} + C_{intruder/i}]^2}$$

$$\sum_{j=1,i\neq j}^{n} V_{Sj} = V_e.R\omega[\sum_{j=1,i\neq j}^{n} C_{ij} + C_{intruder/j}] \approx V_e R\omega \sum_{j=1,i\neq j}^{n} C_{ij}$$

$$\Rightarrow \quad C_{intruder/i} = C_{iS}(.,.,.)_{exp} - C_{iS}(.,.,.)_{ref}$$

B. The intruder **is in contact** with the floor, the capacitive coupling intruder/floor is not negligible.

$$C_{intruder/i} = C_{iS}(.,.,.)_{exp} - C_{iS}(.,.,.)_{ref} - C_{intruder/floor}$$

II Detection and Discrimination Set-up : DISCRIMINATION human/object
Evaluation of the distance intruder/active sensor

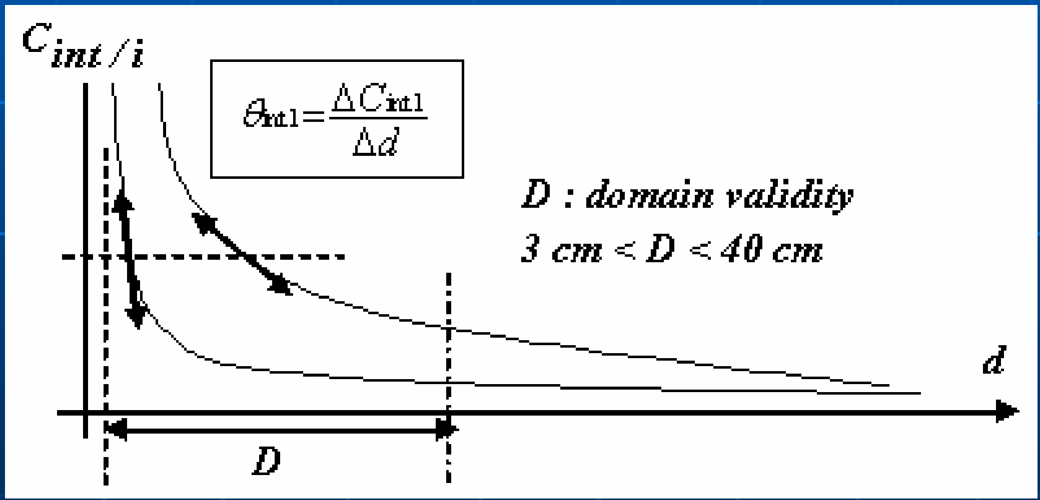
The Coefficient of induction is modelled by:

$$C_{\text{int}\,i} = \varepsilon \frac{S}{d_i}$$

$$\theta_{\text{int}\,i} = \frac{\Delta C_{\text{int}\,i}}{\Delta d} = \frac{C_{\text{int}\,i}(d_i + \Delta d) - C_{\text{int}\,i}(d_i)}{\Delta d}$$

$$\theta_{\text{int}\,i} = \frac{\varepsilon S}{\Delta d}\left[\frac{1}{d_i + \Delta d} - \frac{1}{d_i}\right] \approx -\frac{\varepsilon S}{d_i^2}$$

$$\left|\frac{C_{\text{int/i}}}{\theta_{\text{int/i}}}\right| = d_i \Rightarrow \varepsilon S$$



Localization and discrimination of the intruder

Outline

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- Capacitive coupling
- Coefficients of capacitance and induction
- Implementation and Validation

II. Detection and discrimination set-up (2 slides)
- Detection of an intruder
- Discrimination Human/Object and evaluation of the distance intruder/active sensor

III. Practical implementation and Precaution (2 slides)

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INPI (National institute of intellectual protection) under the number : 0602599 at the date 27/03/06

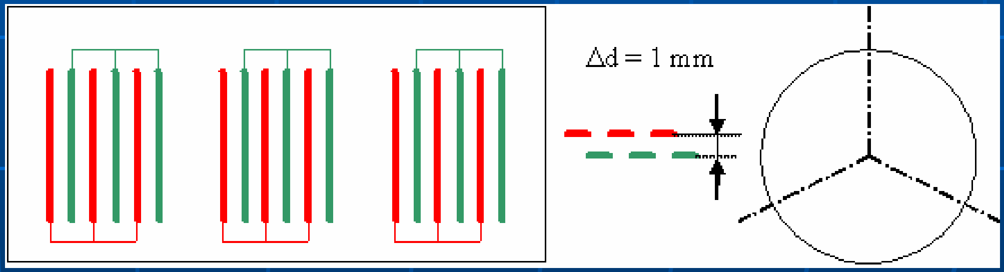
III. PRACTICAL IMPLEMENTATION AND PRECAUTION (1/2)

A. Sensor protection against parasites generated by the robot itself
(electric motor, coders of position, power supply)

- 1st layer : conducting paint at 0Volt
- 2nd layer : isolating paint
- 3rd layer : conducting paint which is a sensor of the safety device

Consequently

- The geometry is adaptable
- The sensor is orientable
- The weight is negligible
- The space hindrance is negligible
- The sensor is cheap

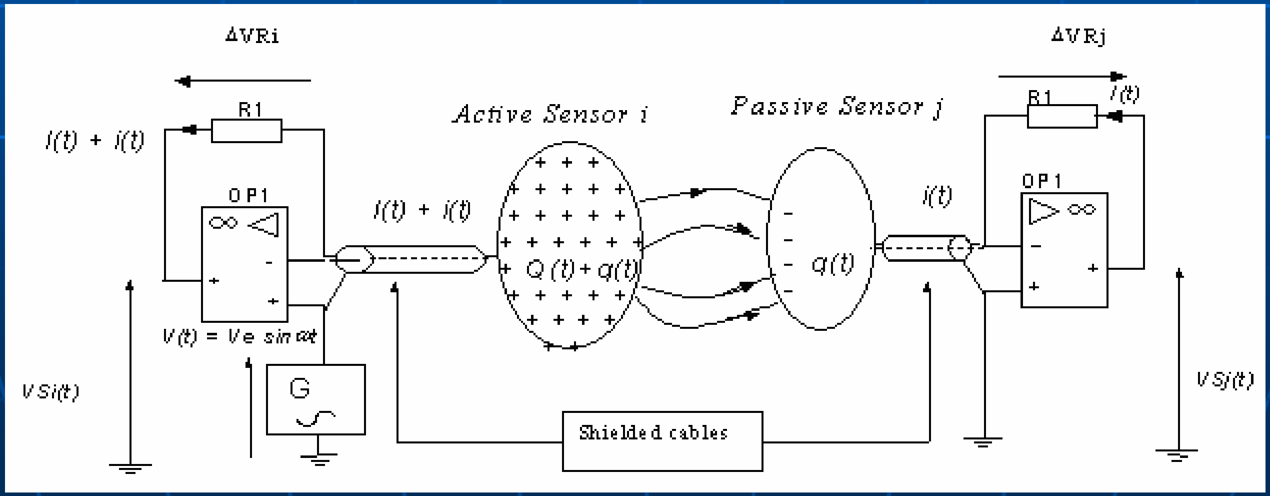


III. PRACTICAL IMPLEMENTATION AND PRECAUTION (2/2)

B. Sensor connection to an integrated linear amplifier :

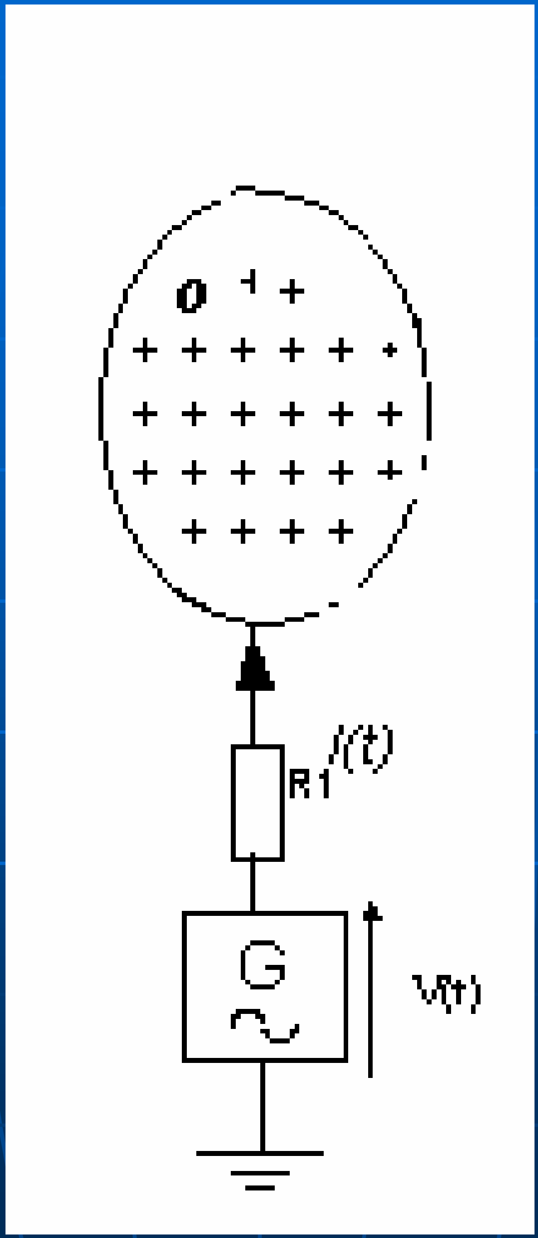
Simple electric wire behaves like a sensor

- inverting input welded on the sensor
- shielded cable,
  - the wire is connected to the inverting input
  - the shielding is connected to the non inverting input

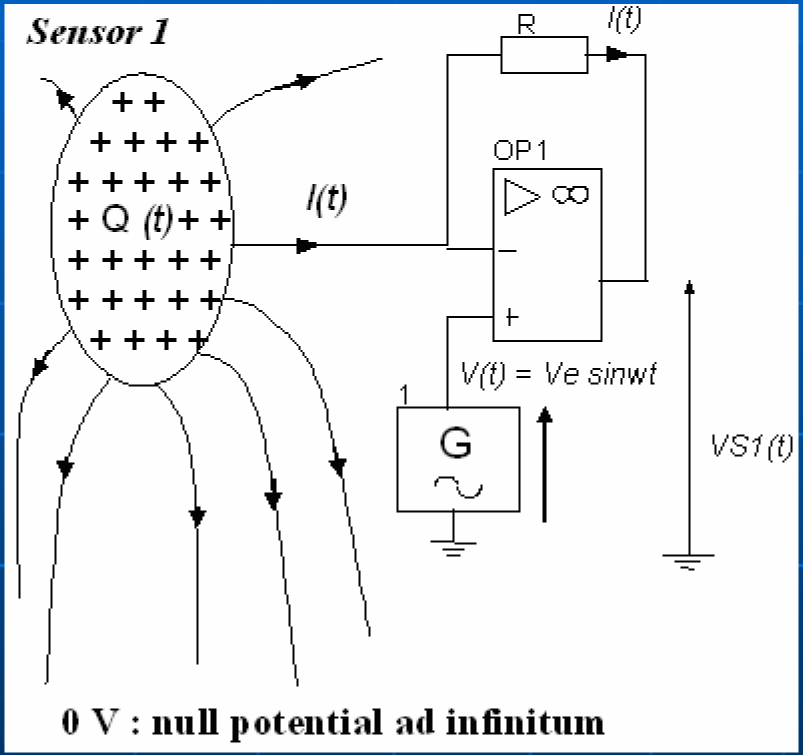


IV. CONCLUSION

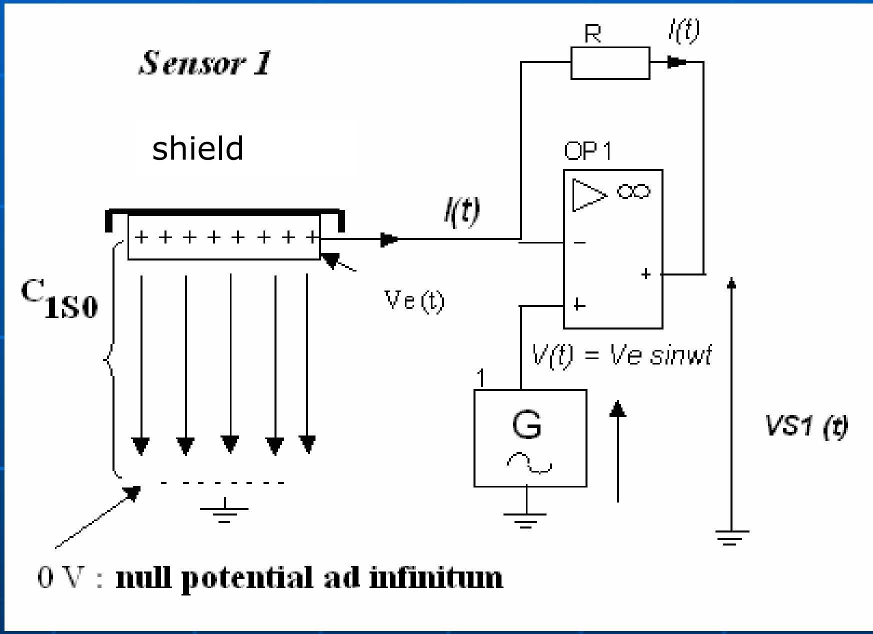
- The set-up is dedicated to safety of people working on automated sites of production.
- It lies on capacitive coupling between a sensor and a target.
- It makes it possible :
  - to detect the presence of an intruder in its environment,
  - to discriminate the nature of the intruder
  - to appreciate the distance of it.
- Industries using automated workshops of production should be interested in this type of safeguarding device.
- It is protected by a french patent to the INPI (National institute of intellectual protection) under the number : 0602599 at the date 27/03/06 .


R1
I(t)
G
V(t)

I. Towards a model :
COEFFICIENTS OF CAPACITANCE AND INDUCTION (1/2)
How to measure ?



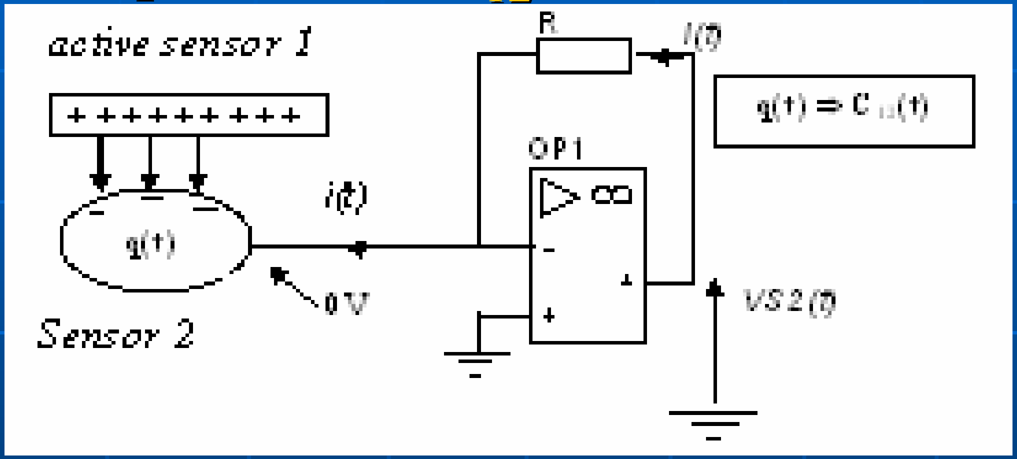
Capacitance C_{11}



Model (1) $$V_{S1} = V_e\sqrt{1+[R\omega C_{11}]^2} = V_e\sqrt{1+(R\omega)^2[C_{1S}(.,.,.)+C_{21}]^2}$$

I. Towards a model :
COEFFICIENTS OF CAPACITANCE AND INDUCTION (2/2)
How to measure ?

Capacitance C_{12}



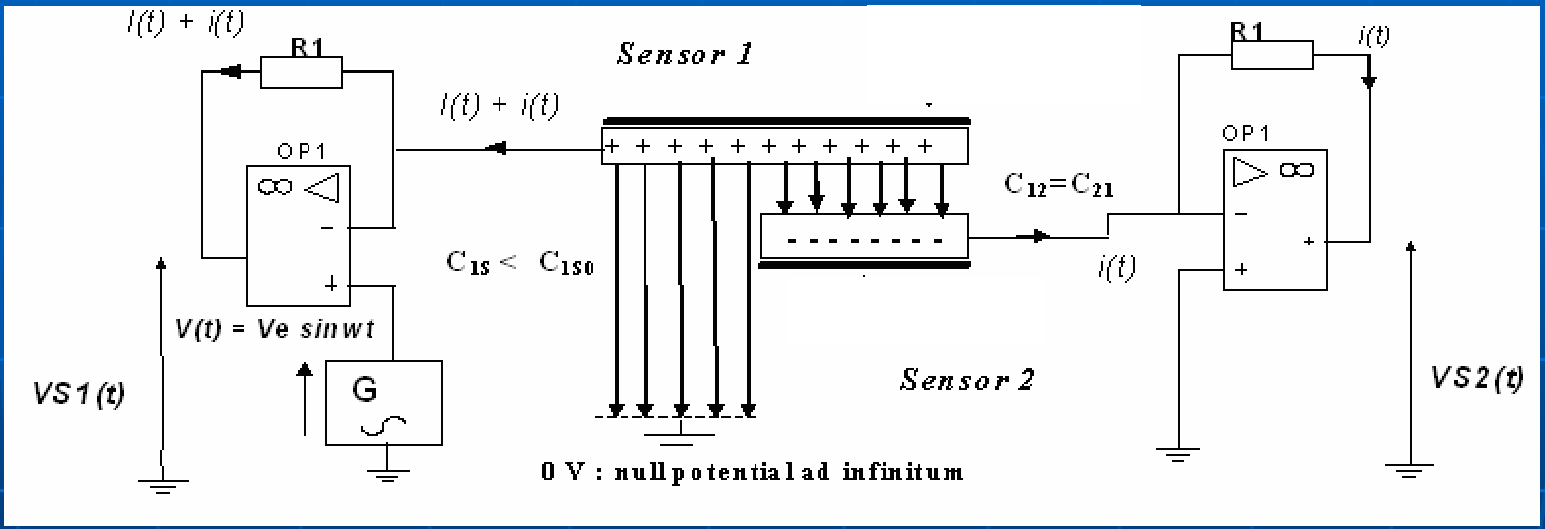
The electric potential V_{S2} (t) gives us access to C_{12}

Model (2) : $V_{S2} = V_e\, R\, \omega\, C_{12}$

I. Towards a model : IMPLEMENTATION, MODELISATION and VALIDATION (1/4)

A. An active 'sensor 1', a 'sensor 2' at a null potential

2 arms of a robot



Model (1) ⇨ $C_{11} = C_{1S}(.,.,.) + C_{21} = \frac{1}{V_e R\omega}\sqrt{V_{S1}^2 - V_e^2}$

Model (2) ⇨ $C_{12} = C_{21} = \frac{1}{V_e R\omega} V_{S2}$

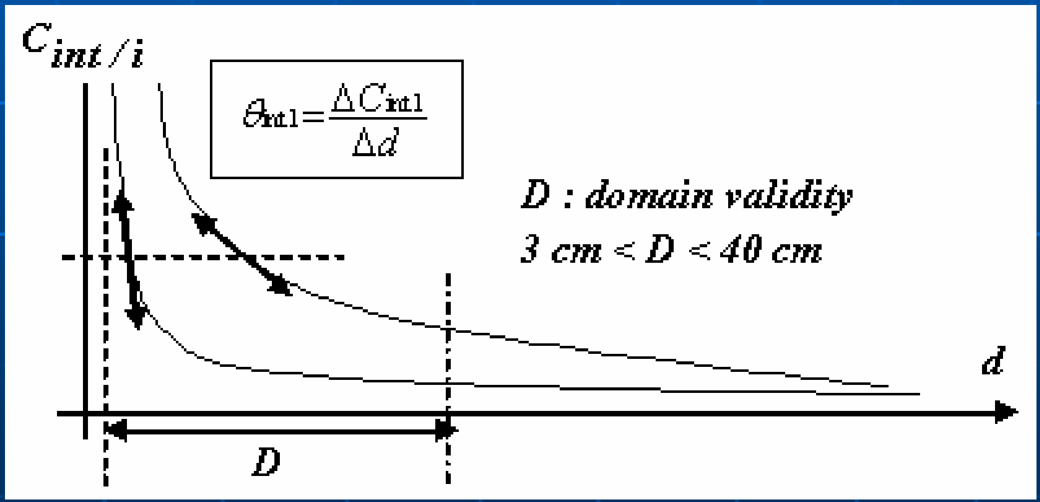
II Detection and Discrimination Set-up : DISCRIMINATION human/object Evaluation of the distance intruder/active sensor

The Coefficient of induction is modelled by : $$C_{\text{int}\,i} = \varepsilon \frac{S}{d_i}$$

$$\theta_{\text{int}\,i} = \frac{\Delta C_{\text{int}\,i}}{\Delta d} = \frac{C_{\text{int}\,i}(d_i + \Delta d) - C_{\text{int}\,i}(d_i)}{\Delta d}$$

$$\theta_{\text{int}\,i} = \frac{\varepsilon S}{\Delta d}\left[\frac{1}{d_i + \Delta d} - \frac{1}{d_i}\right] \approx -\frac{\varepsilon S}{d_i^2}$$

$$\left|\frac{C_{\text{int/i}}}{\theta_{\text{int/i}}}\right| = d_i \Rightarrow \varepsilon S$$



Localization and discrimination of the intruder

II Detection and Discrimination Set-up : DISCRIMINATION human/object Evaluation of the distance intruder/active sensor

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$$\theta_{\text{int}\, i} = \frac{\Delta C_{\text{int}\, i}}{\Delta d} = \frac{C_{\text{int}\, i}(d_i + \Delta d) - C_{\text{int}\, i}(d_i)}{\Delta d}$$

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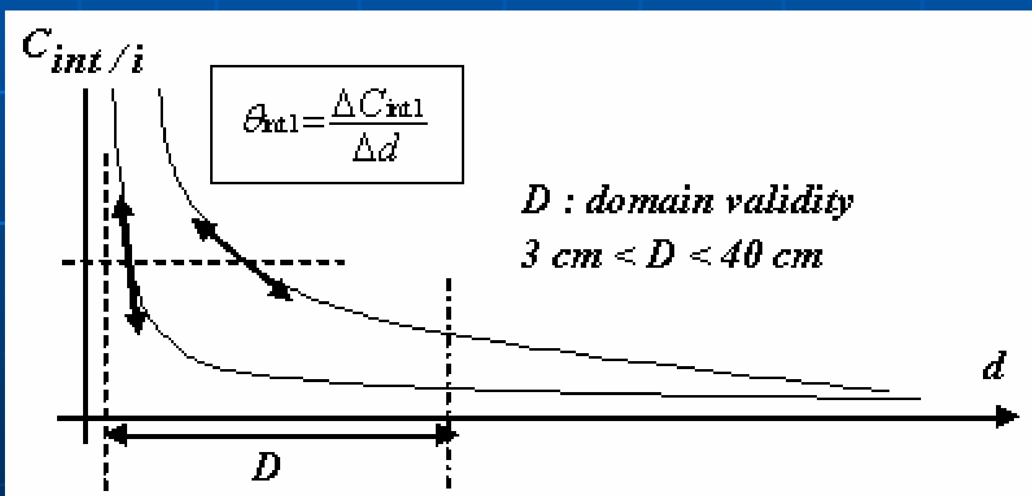
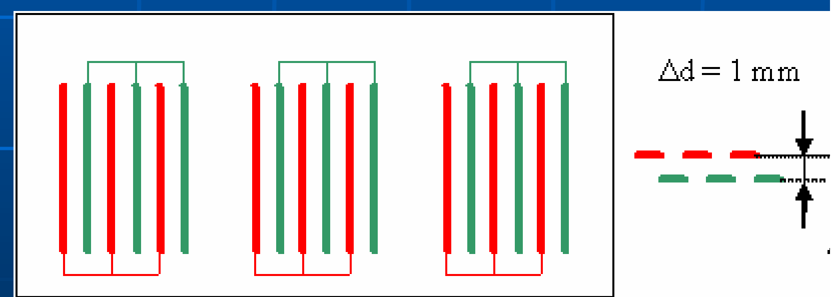


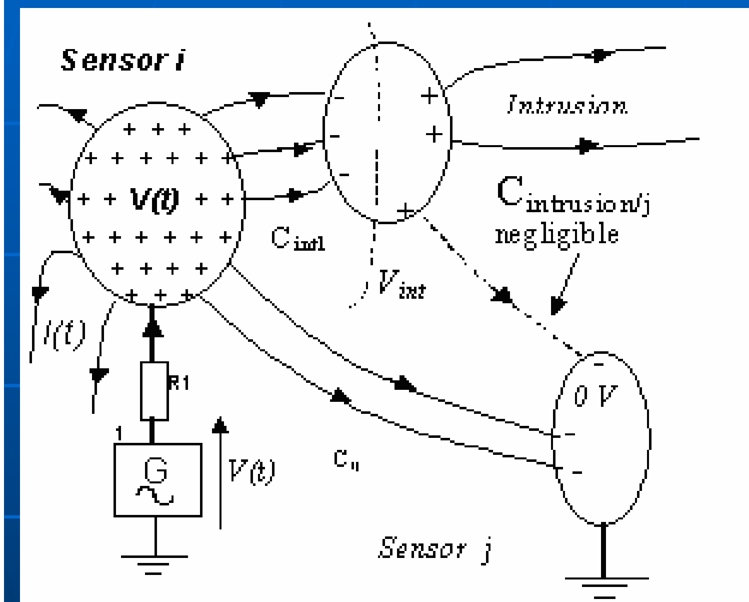
Localization and discrimination of the intruder

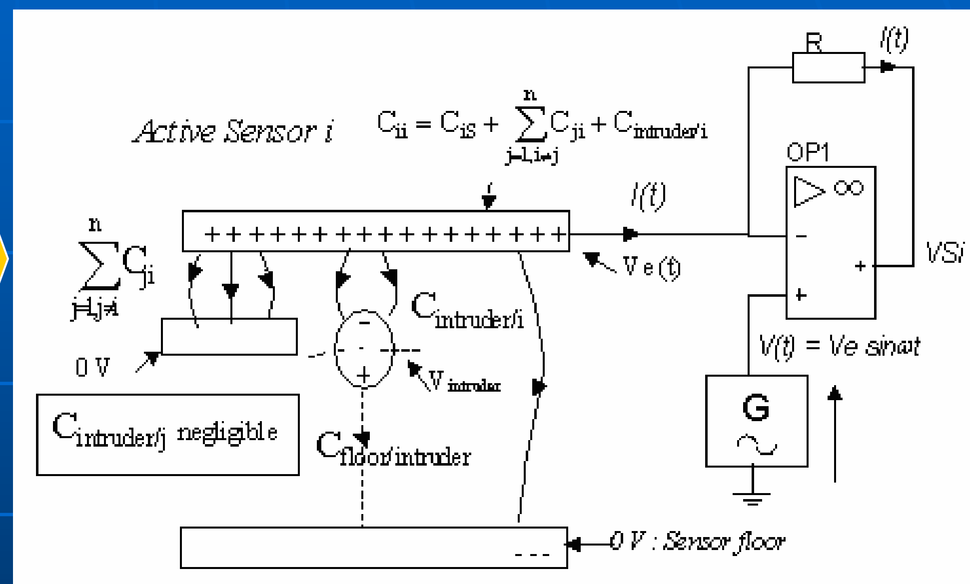


Design : Two identical sensors separated by Δd

II. Detection and Discrimination Set-up: DETECTION OF AN INTRUDER AND VALIDATION (1/3)

A. The intruder is **not in contact** with the floor (far enough), this latter behaves like a ‘sensor j’ at a null potential



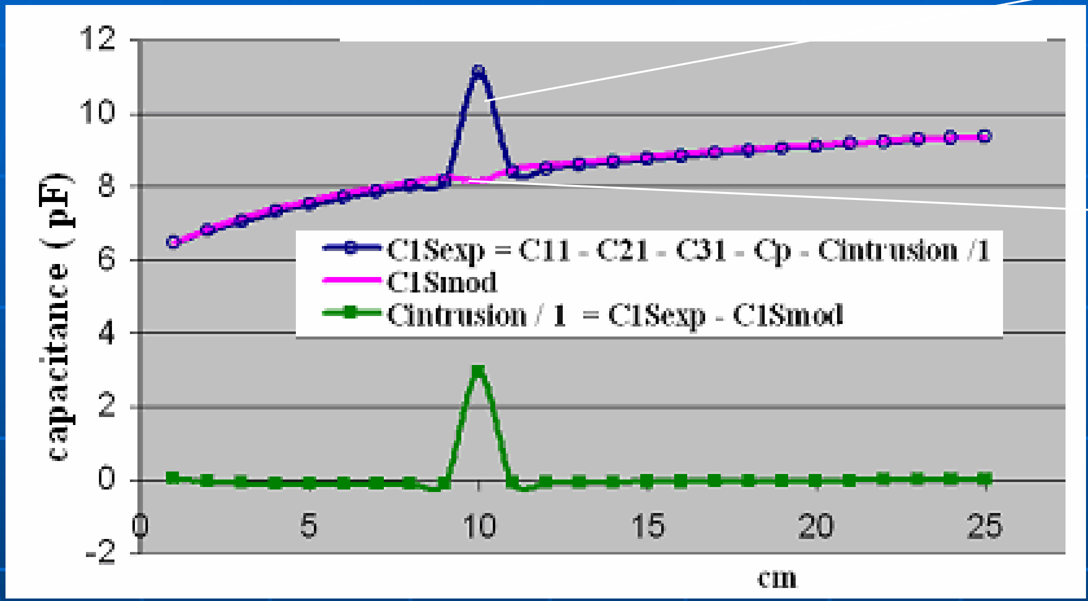


$$V_{Si} = V_e \sqrt{1 + (R\omega)^2 [C_{iS} + \sum_{j=1, i\neq j}^{n} C_{ji} + C_{intruder/i}]^2}$$

$$\sum_{j=1, i\neq j}^{n} V_{Sj} = V_e . R\omega [\sum_{j=1, i\neq j}^{n} C_{ij} + C_{intruder/j}] \approx V_e R\omega \sum_{j=1, i\neq j}^{n} C_{ij}$$

$$C_{intruder/i} = C_{iS}(.,.,.)_{exp} - C_{iS}(.,.,.)_{model}$$

II Detection and Discrimination Set-up :
DETECTION OF AN INTRUDER AND VALIDATION (2/3)



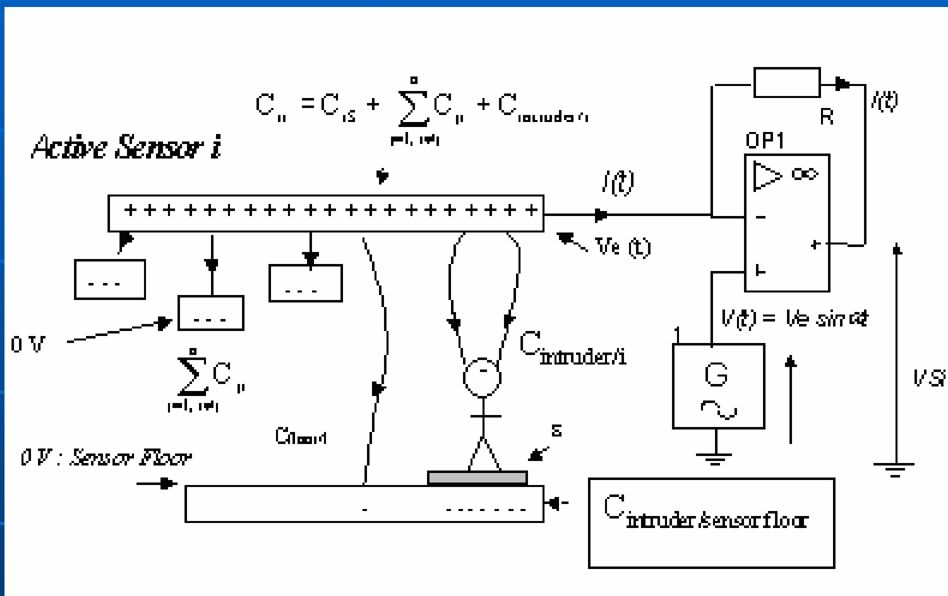
By measuring the potential at the output of the circuit

Reference model

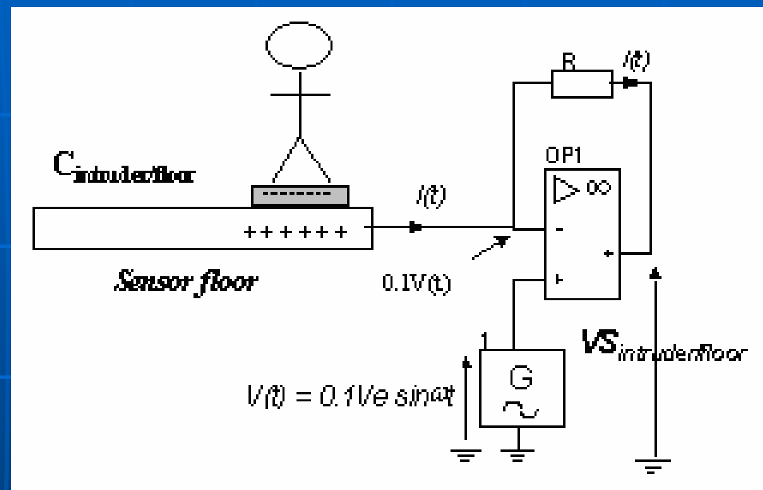
Presence of a human being 10 cm away from an active sensor

II Detection and Discrimination Set-up :
DETECTION OF AN INTRUDER AND VALIDATION (3/3)

B. The intruder **is in contact** with the floor, the capacitive coupling intruder/floor is not negligible.



Detection of an intruder with the floor



Coupling intruder/floor

$$V_{Si} = V_e \sqrt{1+(R\omega)^2[C_{iS} + \sum_{j=1,\, ii}^{n} C_{ji} + C_{intruder/i} - C_{intruder/floor}]^2}$$

$$V_{Sintruder} = V_e . R\omega [C_{intruder/floor}]$$

$$C_{intruder/i} = C_{iS}(.,.,.)_{exp} - C_{iS}(.,.,.)_{mod} - C_{intruder/floor}$$