

Sample Manuscript 1.0

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Index Terms—Electrical capacitance tomography, differential sensor, dynamic range, capacitance measuring circuit, optimization.

I. Method

A. Cylindrical capacitor

The capacitance of a cylindrical capacitor is described by:

$$C_{cc} = \frac{2\pi h \varepsilon_0}{\ln(b/a)} \quad (1)$$

where ε_0 is the dielectric permittivity of air, h is the axial length of active screen, a and b are the radius of measuring electrodes and active screen, respectively.

Therefore, it can be assumed that

$$C_{d1} = C_{d2} = \dots = C_{di} \quad (2)$$

$$C_{cc} = \sum_{i=1}^{n_E} C_{di} \quad (3)$$

where C_{di} is the capacitance between the i^{th} measuring electrode and the active screen.

In consideration of the gaps between measuring electrodes and radial screens and the edge effect caused by finite h , C_{di} can be estimated by:

$$C_{di} = k_c \frac{C_{cc}}{n_E} = \frac{2k\pi h \varepsilon_0}{\ln(b/a)n_E} \quad (4)$$

where k_c is a correction factor related to sensor geometry, n_E is the number of measuring electrodes.

B. Circuit output

Therefore, the output voltage can be described by:

$$V_o(t) = -\frac{j\omega R_f(C_m - kC_{d2})}{j\omega C_f R_f + 1} V_i(t) \quad (5)$$

where ω is the applied angular frequency, R_f and C_f are the feedback resistor and capacitor.

By introducing $k_0 = j\omega R_f / (j\omega C_f R_f + 1)$, Eq(5) can be simplified into:

$$V_o(t) = -k_0(C_m - kC_{d2})V_i(t) \quad (6)$$

C. Noise analysis

In consideration that

$$\begin{aligned} |j\omega R_{s3}(C_m + C_d + C_{s3} + C_{s4})| &\ll 1, \\ |j\omega R_{s4}(C_m + C_d + C_{s3} + C_{s4})| &\ll 1, \\ |j\omega R_f C_f| &\gg 1 \end{aligned}$$

the equations for noise gains can be properly simplified.

The total RMS noise can be expressed by

$$E_t = \sqrt{\sum_{i=1}^q E_n^2(i)[V_{RMS}]} \quad (7)$$

where $E_n(i)$ represents the i^{th} RMS noise source, i.e. the passive elements and the intrinsic noise sources in the op-amp.

Each noise source generates a noise density at the inverting or non-inverting input of the op-amp, which can be calculated by:

$$E_n = \sqrt{\int_0^{\omega_c} |A_n(\omega)|^2 e_n^2(\omega) d\omega [V_{RMS}]} \quad (8)$$

where $A_n(\omega)$ is the noise gain, ω_c is the cut-off frequency of the following conditioning circuit.

D. Sensitivity distribution

In ECT, the sensitivity distribution of electrode pair (i, j) $\mathbf{S}_{i,j}(k)$ is defined as:

$$\mathbf{S}_{i,j}(k) = \mu(k) \frac{C_{i,j}(k) - C_{i,j}^l}{\Delta C_{i,j} \Delta \varepsilon} \quad (9)$$

where

$$\Delta C_{i,j} = C_{i,j}^h - C_{i,j}^l \quad (10)$$

$$\Delta \varepsilon = \varepsilon^h - \varepsilon^l \quad (11)$$

and where $C_{i,j}(k)$ is the capacitance when the k^{th} element has the high dielectric constant ε^h and all the other elements have low dielectric constant ε^l . And $C_{i,j}^h$ and $C_{i,j}^l$ are the capacitances when the pipe is filled with high and low permittivity materials, respectively. $\Delta C_{i,j}$ is, therefore, the full scale capacitance range.