

## Approximation of the current-voltage diode characteristic using a Fuzzy Logic System

**Objectives:** understanding the motivation behind using FLSs as universal approximators, experimenting the connection between input and output fuzzy sets and the rule base, understanding fuzzification/inference/defuzzification, creating a complete FLS for the approximation of a given function.

**Note:** MATLAB/Simulink is accessed online (<https://matlab.mathworks.com/>), by logging in with the MS Teams student credentials ([surname.name@student.utcluj.ro](mailto:surname.name@student.utcluj.ro)).

**Terms and abbreviations:** *function approximation, function modelling.*

### ○ Fuzzy logic systems as universal approximators

One of the most important applications of fuzzy logic systems is function approximation. Let  $\mathbf{y} = \mathbf{f}(\mathbf{x})$  be a graphical function, with an approximate analytic representation. One can design a FLS with  $\mathbf{x}$  as input and  $\mathbf{y}$  as output, so that the difference  $\mathbf{e}$  between the estimated value of  $\mathbf{y}$ ,  $\mathbf{y}_{est}$ , and  $\mathbf{f}(\mathbf{x})$ , is as small as required.

$$|y_{est} - f(x)| < e$$

The fuzzy logic system with the input  $\mathbf{x}$  and the output  $\mathbf{y}$  is a **universal approximator for graphical functions  $\mathbf{y}=\mathbf{f}(\mathbf{x})$** .

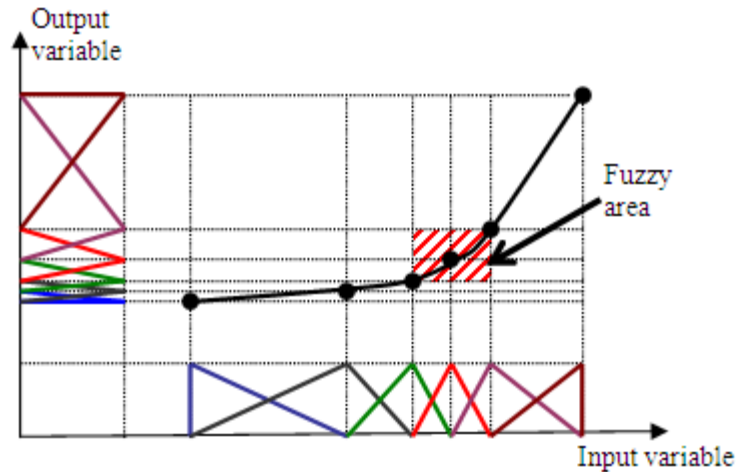
### ○ Fuzzy modelling of the current-voltage diode characteristic

The goal is to approximate the forward bias region of the current-voltage (i-v) characteristic of a semiconductor diode, based on the i-v plot, obtained either through experiments or from the datasheet. The FLS is described as follows:

- **Input variable** – values of the voltage drop across the diode in forward bias,  $v = v_{AK}$ , between [0 mV, 860 mV]
- **Output variable** – values of the forward current through the diode,  $i = i_A$ , between [0 mA, 450 mA]

The FLS completely describes the electrical behaviour of the diode in forward bias, for  $v = v_{AK}$ , between [0 mV, 860 mV], ignoring temperature, humidity and technological deviations variations. Thus, the FLS can be used as an electrical model of the diode.

The principle behind modelling the i-v diode characteristic is based on covering the non-linear curve with “fuzzy areas”:



Each “fuzzy area” is described by:

- a fuzzy set over the universe of discourse for the input variable  $v$ , denoted  $MFV_k$
- a fuzzy set over the universe of discourse for the output variable  $i$ , denoted  $MFik$
- a fuzzy rule  $R_k$ , that indicates the fact that the two fuzzy sets  $MFV_k$  and  $MFik$  are connected through a fuzzy relation

$$R_k: \text{If } v \text{ is } MFV_k, \text{ then } i \text{ is } MFik$$

Note: For the highly non-linear regions of the plot, it is necessary to use more fuzzy sets for input and output.

#### ○ FLS for modelling the i-v diode characteristic

The FLS for modelling the i-v diode characteristic consists of:

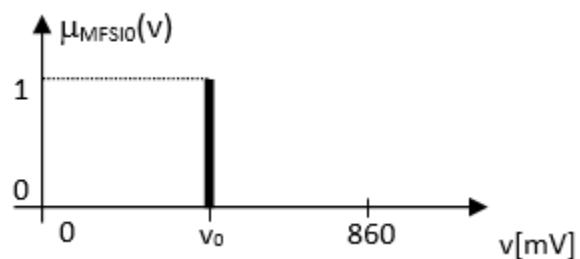
- the fuzzy sets over the universe of discourse for the input variable  $v$ , denoted  $MFV_k$
- the fuzzy sets over the universe of discourse for the input variable  $i$ , denoted  $MFik$
- the fuzzy rule base, with  $k$  rules:  $R_k$ : : If  $v$  is  $MFV_k$ , then  $i$  is  $MFik$

The components of the FLS and the operations that turn a crisp input ( $v = v_0$  – voltage drop across the diode) into a crisp output ( $i = i_0$  – current through the diode) are shown in the figure.

The operation of the FLS are:

- **fuzzification** - transforming a crisp input value into a singleton input fuzzy set, with the following membership function:

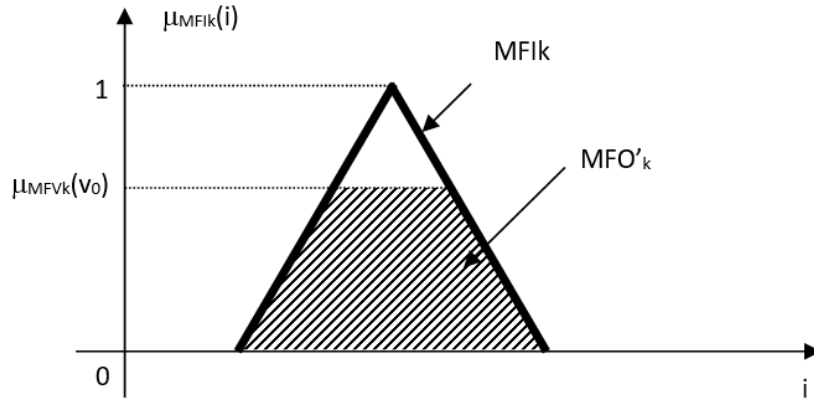
$$\mu_{MSFI_0}(v) = \begin{cases} 1, & v = v_0 \\ 0, & v \neq v_0 \end{cases}$$



- **inference** - computing the  $Y_k$  result of each  $R_k$  rule, based on the fuzzy input value and on each  $R_k$  rule, and using the *min* (Mamdani) implication method:

$$\mu_{MFO'_k}(i) = \min(\mu_{MFV_k}(v_0), \mu_{MFI_k}(i))$$

The output fuzzy set for the rule  $R_k$  (partial conclusion) is:

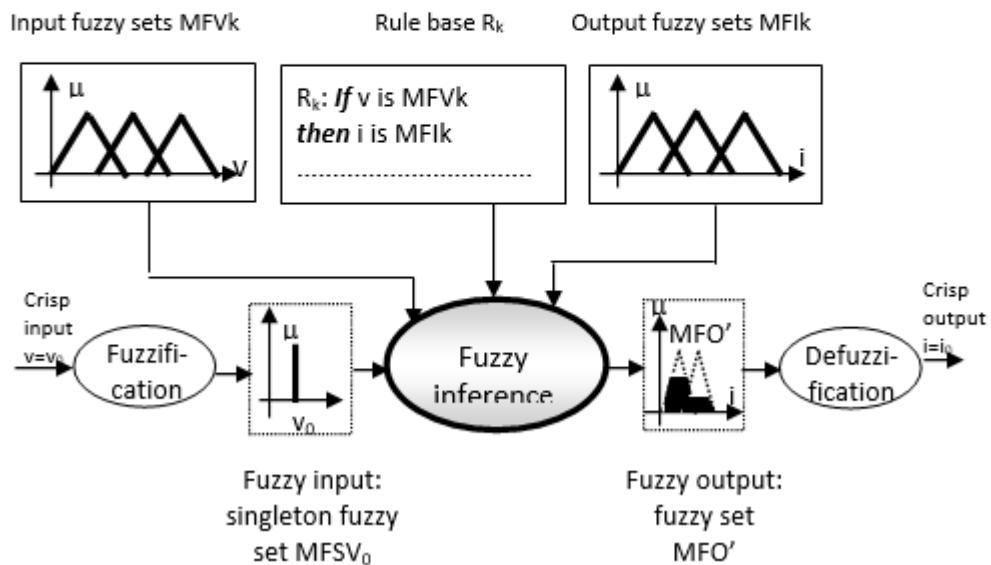


Aggregating the partial results is done using *max* (union) operator:  
 $\mu_{MFO'}(i) = \max_k \mu_{MFO'_k}(i)$ , equivalent to  $MFO' = \cup_k MFO'_k$ .

- **defuzzification** – the opposite of fuzzification. It extracts a crisp value from the output fuzzy set, obtained in the inference process.

**Notations:**

- = operation
- = component
- = fuzzy representation of the input/output variable



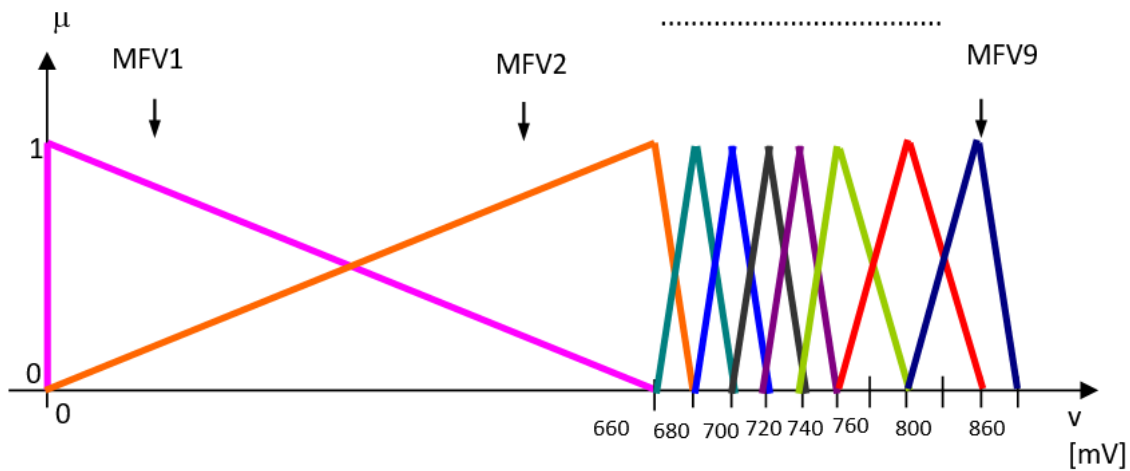
- Creating the FLS

**Exercise 1**

Implement the FLS with one input and one output, using *Fuzzy Logic Designer*. The specifications are:

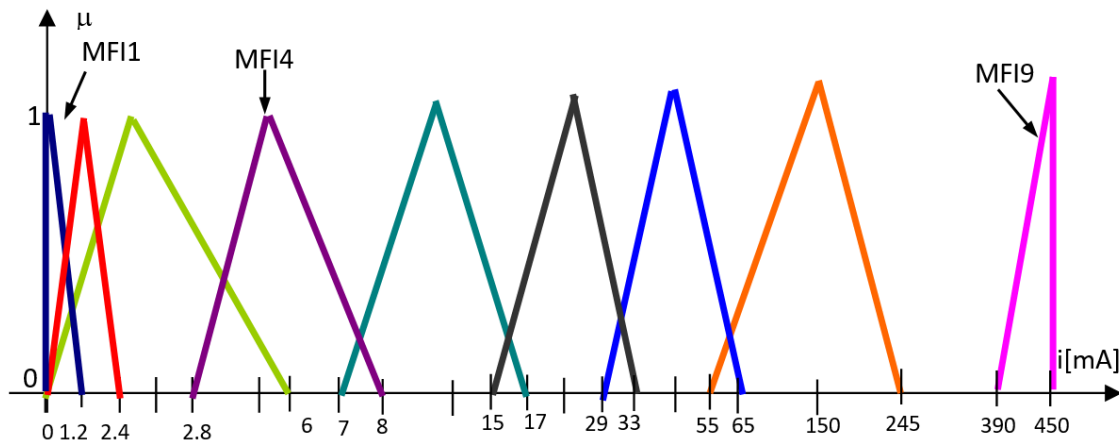
- Input variable  $v$ , 9 triangular fuzzy sets, denoted  $MFV_k$ ,  $k = 1, 2, \dots, 9$ , with the following parameters:

MFV1 - [0 0 680]	MFV2 - [0 680 690]	MFV3 - [680 690 700]
MFV4 - [690 700 720]	MFV5 - [700 720 740]	MFV6 - [720 740 760]
MFV7 - [740 760 800]	MFV8 - [760 800 860]	MFV9 - [800 860 860]



- output variable  $i$ , 9 triangular fuzzy sets, denoted  $MFi_k$ ,  $k = 1, 2, \dots, 9$ , with the following parameters:

MF11 - [0 0 1.2]	MF12 - [0 1.2 2.4]	MF13 - [0 2.4 6]
MF14 - [2.8 6 8]	MF15 - [7 12 17]	MF16 - [15 24 33]
MF17 - [29 47 65]	MF18 - [55 150 245]	MF19 - [390 450 450]



- rule base with 9 rules as: *If  $v$  is  $MFV_k$  then  $i$  is  $MFi_k$ ,  $k = 1, 2, \dots, 9$*

Save the FLS under the name "*diode.fis*".

Visualize the input-output curve (voltage-current). Set the number of plot points to 100. Compare it to the original characteristic.

### Exercise 2

Test the fuzzy system for a series of crisp input values:

$v = \{0 \text{ mV}; 650 \text{ mV}; 675 \text{ mV}; 700 \text{ mV}; 725 \text{ mV}; 750 \text{ mV}; 775 \text{ mV}; 800 \text{ mV}; 850 \text{ mV}\}$ . Write down the output values.

### Exercise 3

Write a script that plots the current-voltage characteristic, using *readfis*, *evalfis*, *plot*.

Note: for *evalfis*, set *NPts* = 10000

### Exercise 4

Identify the areas of the plot in which the approximation errors are high. Change the initial FLS to reduce these errors. Save the new FLS. Display the initial and improved current-voltage characteristic on the same plot.