



Design and Simulation of Fuzzy Implication Function of Fuzzy System Using Two Stage CMOS Operational Amplifier

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Abstract: This paper presents the design methods for the designing and simulation of implication function (mamdani) using two stage CMOS operational amplifier in SPICE. This paper also presents how the first three steps of fuzzy system i.e. fuzzification, rule composition and implication process are merged and get the output for each rule. I have also calculated the electrical parameters like slew rate, common mode rejection ratio, gain, power dissipation and resistances for each rule.

Keywords: Two stage CMOS operational amplifier, Fuzzy system, Implication process, SPICE

I. Introduction

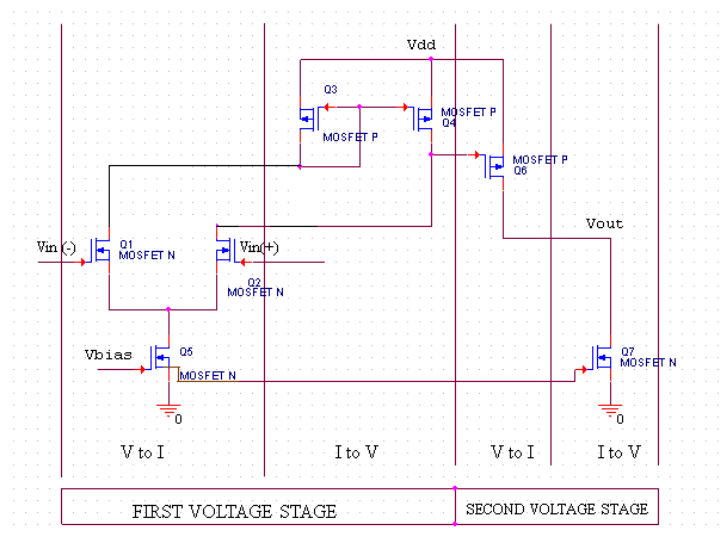
An operational amplifier (op-amp) is a direct coupled high gain amplifier usually consisting of one or more differential amplifiers and usually followed by a level translator and an output stage. The output stage is generally a push pull or push pull complementary symmetry pair. The op-amp is a versatile device that can be used to amplify dc as well as ac input signals and was originally designed for computing such mathematical functions as addition, subtraction, multiplication, and integration [1, 2].

Main target is to design the 2 stage operational amplifier. It consists of four different stages [3] :

1. Classic Differential amplifier (voltage to current)
2. Differential to single ended load (Current mirror) (current to voltage)
3. Transconductance Grounded gate (voltage to current)
4. Class A (source or sink load) (current to voltage)

The circuit diagram of two stage CMOS operational amplifier with its division in 4 stages [3] is shown in Fig 1.

Figure 1 : Two stage CMOS operational amplifier



There are some electrical parameters which I have calculated for implication process i.e. mamdani which are as follows [1] :

- **Differential Input Resistance:** Differential input resistance is the equivalent resistance that can be measured at either the inverting or non-inverting input terminal with the other terminal connected to ground.
- **Output Resistance :** Output resistance is the equivalent resistance that can be measured between the output terminal of the op-amp and the ground.
- **Large Signal Voltage Gain :** Since the op-amp difference voltage between two input terminals, the voltage gain of the amplifier is defined as the ratio of output voltage to differential input voltage. That is

$$A = \frac{V_o}{V_{id}}$$

Because output signal amplitude is much larger than the input signal, the voltage gain is commonly called large signal voltage gain.

- **Common mode rejection ratio(CMRR):** It is defined as the ratio of differential gain to common mode gain. A high CMRR helps to reject common mode signals such as noise successfully.

$$CMRR = A_d / A_{cm}$$

$$CMRR \text{ (dB)} = 20 \log(A_d / A_{cm})$$

- **Slew rate (SR):** It is defined as the maximum rate of change of output voltage per unit time and it is expressed in volts/ microseconds.

$$SR = \max [dV_o / dt]$$

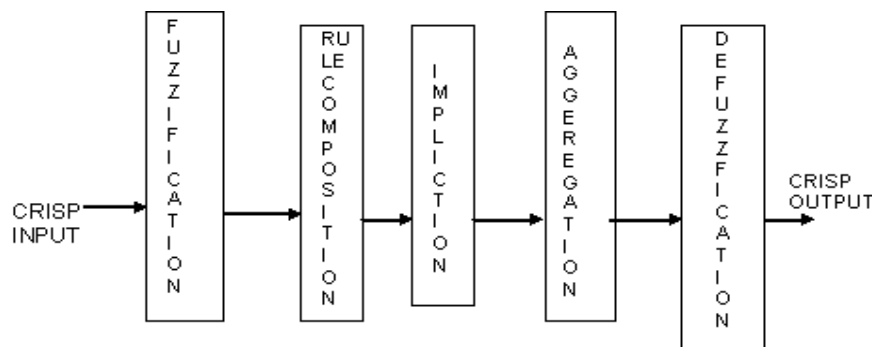
Fuzzy logic is a powerful problem solver methodology with wide range of applications in industrial control, consumer electronics, management, medicine, expert system and information technology [4]. It provides a simple way to draw definite conclusions from vague, ambiguous or imprecise and incomplete information. It is a natural way of making a decision and is very close to the way the human beings think and make decision even under highly uncertain environments [5,6].

In this paper I will discuss regarding the designing and electronic implementation of implication process (mamdani) using 2 stage CMOS operational amplifier and simulating it with PSPICE software [7-9].

II. Fuzzy System

There are five parts of the fuzzy system shown in Fig 2. Fuzzification of the input variables, application of the fuzzy operator (AND or OR) in the antecedent, implication from the antecedent to the consequent, aggregation of the consequents across the rules, and defuzzification.

Figure 2 : Fuzzy System



Step 1 : Fuzzification : The first step is to take the inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions. In the Fuzzy Logic, the input is always a crisp numerical value limited to the universe of discourse of the input variable and the output is a fuzzy degree of membership in the qualifying linguistic set (always the interval between 0 and 1).

Step 2 : Apply Fuzzy operator : Rule Composition : Once the inputs have been fuzzified, we know the degree to which each part of the antecedent has been satisfied for each rule. If the antecedent of a given rule has more than one part, the fuzzy operator is applied to obtain one number that represents the result of the antecedent for that rule. This number will then be applied to the output function. The input to the fuzzy operator is two or more membership values from fuzzified input variables. The output is a single truth value.

There are different fuzzy operators : AND methods are supported: min (minimum) and prod (product), OR methods are also supported: max (maximum), and the probabilistic OR method probor.

Step 3 : Implication : Before applying the implication method, we must take care of the rule's weight. Every rule has a weight (a number between 0 and 1), which is applied to the number given by the antecedent. Generally this weight is 1 and so it has no effect at all on the implication process. From time to time we may want to weight one rule relative to the others by changing its weight value to something other than 1.

Once proper weighting has been assigned to each rule, the implication method is implemented. A consequent is a fuzzy set represented by a membership function, which weights appropriately the linguistic characteristics that are attributed to it. The consequent is reshaped using a function associated with the antecedent (a single number). The input for the implication process is a single number by the antecedent, and the output is a fuzzy set. Implication is implemented for each rule.

Step 4 : Aggregation : Since decision are based on the testing of all of the rules in an FIS, the rules must be combined in some manner in order to make a decision. Aggregation is the process by which the fuzzy sets that represents the output variable, just prior to the fifth and final step, Defuzzification. The input of the aggregation process is the list of truncated output functions returned by the implication process for each rule. The output of the aggregation process is one fuzzy set for each output variable. Different types of aggregation functions are max (maximum), probor (probabilistic OR) and sum (simply the sum of each rule's output set).

Step 5 : Defuzzification : The input for the defuzzification process is a fuzzy set (the aggregate output fuzzy set) and the output is a single number. As much as fuzziness helps the rule evaluation during the intermediate steps, the final desired output for each variable is generally a single number. However, the aggregate of a fuzzy set encompasses a range of output values and so must be defuzzified in order to resolve a single output value form the set. Perhaps the most popular defuzzification method is the centroid calculation, which returns the center of area under the curve.

III. Methodology

Our aim is to design and implementation of fuzzy implication processes which are of different types. The process of shaping of the consequent variable based upon antecedent is called implication. The If-Then rules for fuzzy logic can be written as If <fuzzy proposition (antecedent part) > Then <fuzzy proposition (consequent part)>. The propositional variables A and B are replaced by fuzzy propositions i.e rule composition that is fuzzy *union* (OR or MAX), fuzzy *intersection* (AND or MIN) and fuzzy *complement*. The implication process can be replaced by different styles shown in Table 1 [10].

Table.1 Different types of Implication Styles

S.No.	Implication Process	Formula
1	Larsen	$x \rightarrow y = xy$
2	Lukasiewicz	$x \rightarrow y = \min\{1, 1 - x + y\}$
3	Mamdani	$x \rightarrow y = \min\{x, y\}$
4	Standard Strict	$x \rightarrow y = 1$ if $x \leq y$ 0 otherwise
5	Godel	$x \rightarrow y = 1$ if $x \leq y$ y otherwise
6	Gaines	$x \rightarrow y = 1$ if $x \leq y$ y/x otherwise
7	Kleene-Dienes	$x \rightarrow y = \max\{1 - x, y\}$
8	Kleene-Dienes-Euk.	$X \rightarrow y = 1 - x + xy$

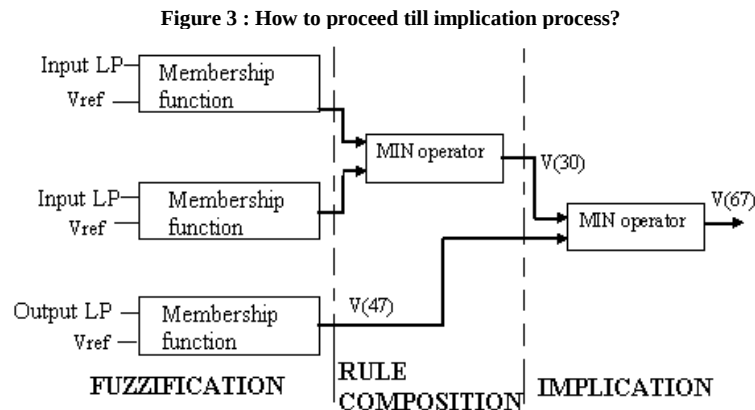
Out of which mamdani style is popularly used. Mamdani proposed a fuzzy implication rule for fuzzy control in 1977.

The problem is to estimate risk involved in an engineering project. Let's assume inputs as project funding and project staffing and output as risk. The linguistic variables defined for *project funding* (A) are **inadequate**, **marginal** and **adequate**, for *project staffing* (B) are **small**, **medium** and **large**, while, for *risk* (C) are **low**, **medium** and **high**. Let's assume the sigma function for all linguistic variables. Then we define the range of each linguistic variable : inadequate as 0-4, marginal as 3-7 and adequate as 6-10. Similarly, for every input and output function. Let's define these ranges in volts so as to implement electronically: inadequate as 1V, marginal as 2V and adequate as 3V. Similarly, I have defined the rages in volts for rest linguistic variables in 1V-3V range. I have assumed reference voltage as 4V and the two stage CMOS operational amplifier works at 6V.

Now second step was rule composition i.e. IF-THEN statement. There are different operators like AND (min), OR (max) and inverter. The rules are :

- IF project funding is inadequate AND project staffing is medium THEN risk is high.
- IF project funding is marginal AND project staffing is large THEN risk is low.
- IF project funding is adequate AND project staffing is medium THEN risk is low.

Before THEN and after IF is known as antecedent part and after THEN is consequent part. Antecedent part is rule composition part and consequent part is *implication process*. Implication process is of different types but in this paper we define mamdani implication style. Fig 3 shows implication process is implemented including fuzzification and rule composition steps. Input LP signifies input linguistic parameter or input linguistic variable.



As seen from Fig 4 a two input MIN circuit can be designed by using the output of a diode logic AND circuit as the input to the non-inverting terminal of a two stage CMOS op-amp.

Let V_1 and V_2 be the two voltage inputs to two similar diodes D_1 and D_2 respectively. The voltage obtained at node A is the output of the AND logic gate and is therefore the minimum of the two voltages V_1 and V_2 . If $V_2 < V_1$, then V_2 will appear at node A. However, the actual voltage at node A, V_A will be $V_2 + V_\gamma$ where V_γ is the cut-in voltage of the diode. This voltage will be the input to the non-inverting terminal of the op-amp. For an effective gain of 1, the output of the op-amp will be V_A which is $V_2 + V_\gamma$. In order to obtain V_2 at the output, a diode D_3 , and a resistance R_L are connected in series at the output of the op-amp and the output, V_O is measured across the resistance R_L , and ground and is equal to V_2 because D_3 provides a voltage drop of V_γ .

Figure 4 :Electronic implementation of MIN function using two stage CMOS op-amp

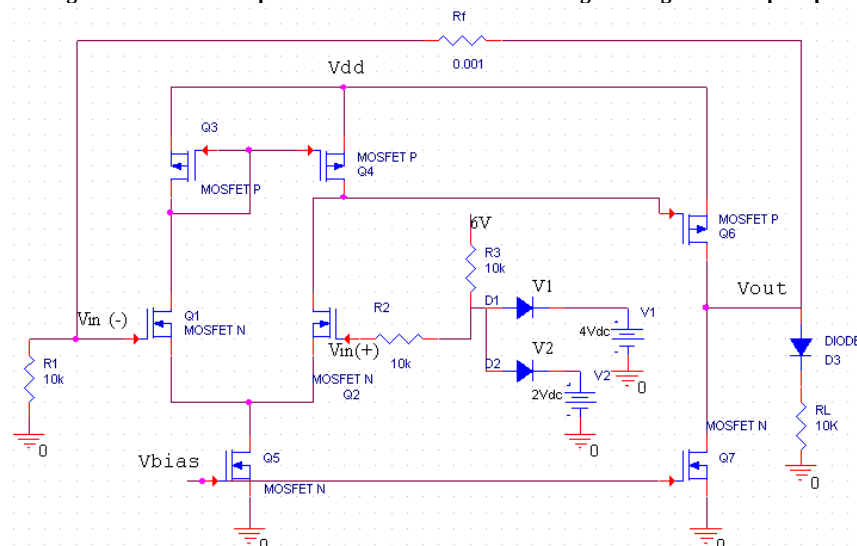
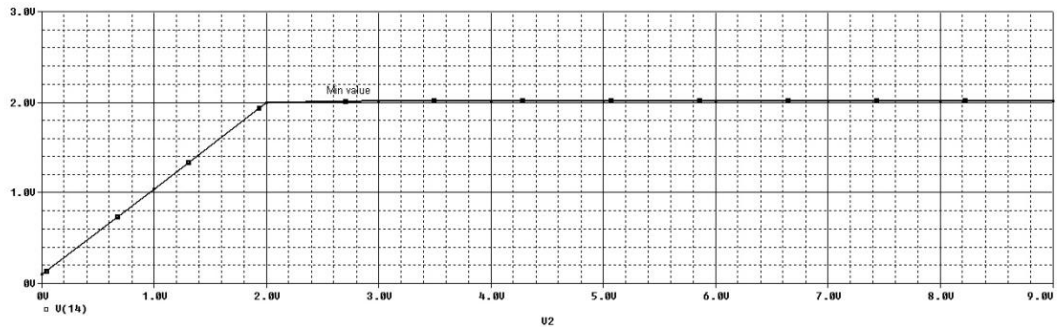


Figure 5 : Output of MIN function



For $V_2 < V_1$

Voltage at node A, $V_A = V_2 + V_\gamma$

$$V_O = V_A$$

Voltage developed across D_3 , $V_{D3} = V_\gamma$

Now $V_O = V_O - V_{D3}$

$$= V_A - V_\gamma$$

$$= V_2 + V_\gamma - V_\gamma$$

Therefore $V_O = V_2$, which is required output.

Now let us assume that $V_2 = 2$ volts and $V_1 = 4$ volts, then the fig 5 circuit will give us

$$V_O = \text{MIN}(4, 2) \\ = 2 \text{ volts}$$

After calculations W/L ratio for fig 4 is coming out as $\frac{W_3}{L_3} = \frac{W_4}{L_4} = \frac{200}{25} = \frac{8\mu\text{m}}{1\mu\text{m}}$; this is $\frac{W}{L}$ ratio for the **current mirror**. $\frac{W_1}{L_1} = \frac{W_2}{L_2} = \frac{18.41\mu\text{m}}{1\mu\text{m}}$; this W/L is for **differential input**; $\frac{W_5}{L_5} = \frac{W_7}{L_7} = \frac{90.9\mu\text{m}}{1\mu\text{m}}$; this W/L is for **current sink**.

Electronically rules are used as

- IF project funding is inadequate (1V) AND project staffing is medium (2V) THEN risk is high (3V).
- IF project funding is marginal (2V) AND project staffing is large (3V) THEN risk is low (1V).
- IF project funding is adequate (3V) AND project staffing is medium (2V) THEN risk is low (1V).

I have implemented all these rules electronically and, get their output. Fig 6, Fig 7 and Fig 8 shows the corresponding output of the first, second and third rule respectively after the implication process. V(30) is the output of rule composition, V(47) is the output of consequent part and V(67) is the final output after mamdani implication process.

I have also calculated their electrical parameters like slew rate, CMRR, gain, output resistance, power dissipation, and input resistance. For all the rules power dissipation is 0.82W, input resistance is $1e+4$, output resistance is $1.93e-2$. Rest the values of slew rate, gain and CMRR is shown in Table 2.

Figure 6 : Output corresponding to first rule.

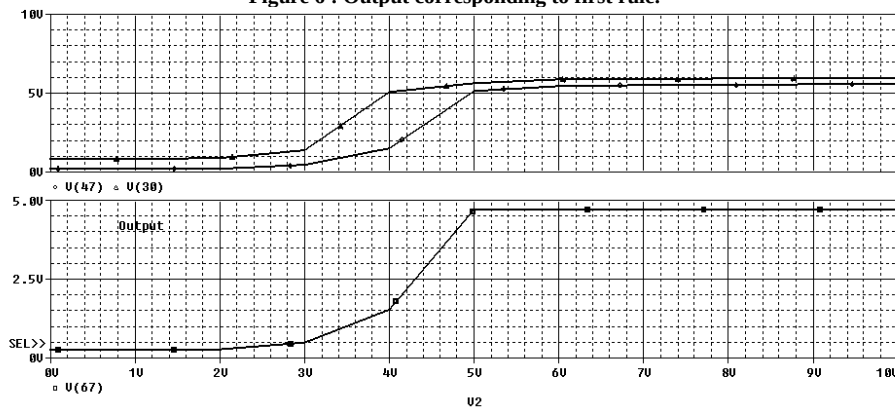


Figure 7: Output corresponding to second rule.

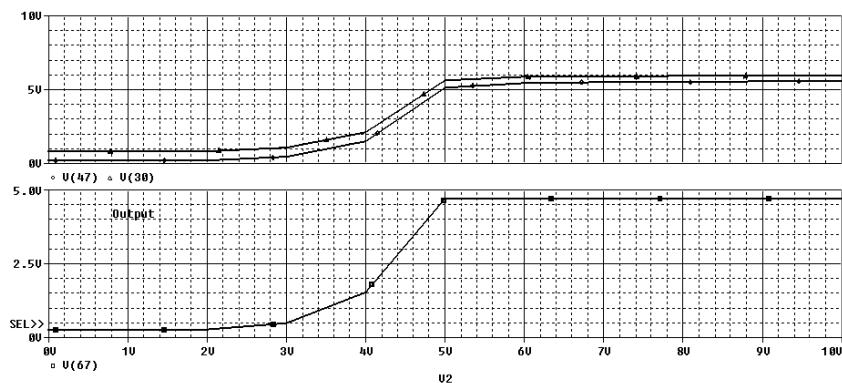


Figure 8: Output corresponding to third rule.

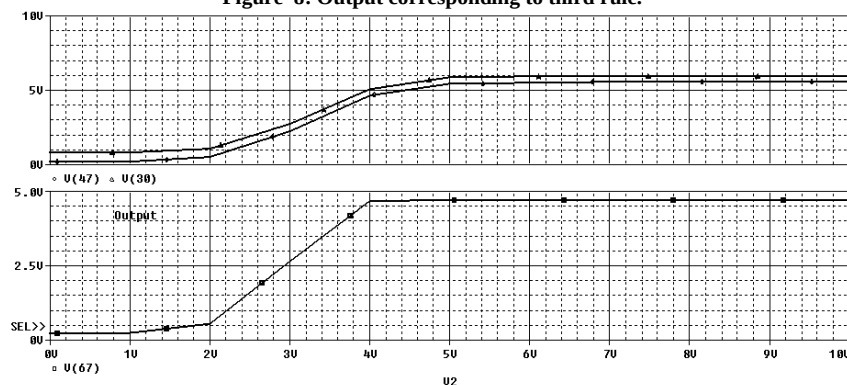


Table 2: Table showing the slew rate, CMRR and gain

	Slew rate (V/ μ sec)	Gain	CMRR (dB)
A =1V, B= 2V, C= 3V	2.4	2.145	2.28
A =2V, B= 3V, C= 1V	2.45	1.622	4.71
A =3V, B= 2V, C= 1V	2.43	1.62E-02	44.71

So, I have successfully implemented the mamdani implication function along with the three steps of fuzzy system i.e. fuzzification, rule composition and implication.

IV. Conclusion

In this paper an attempt has been made for designing the fuzzy implication function and its electronic implementation using two stage CMOS operational amplifier. I have successfully designed and implemented the corresponding function. Along with this I have clubbed the first three steps of fuzzy system i.e. fuzzification, rule composition and implication process for various rules. I have also calculated its various parameters like slew rate, CMRR, power dissipation, gain, input resistance and output resistance for every rule. In future, I will try for fourth step i.e. aggregation.

V. References

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