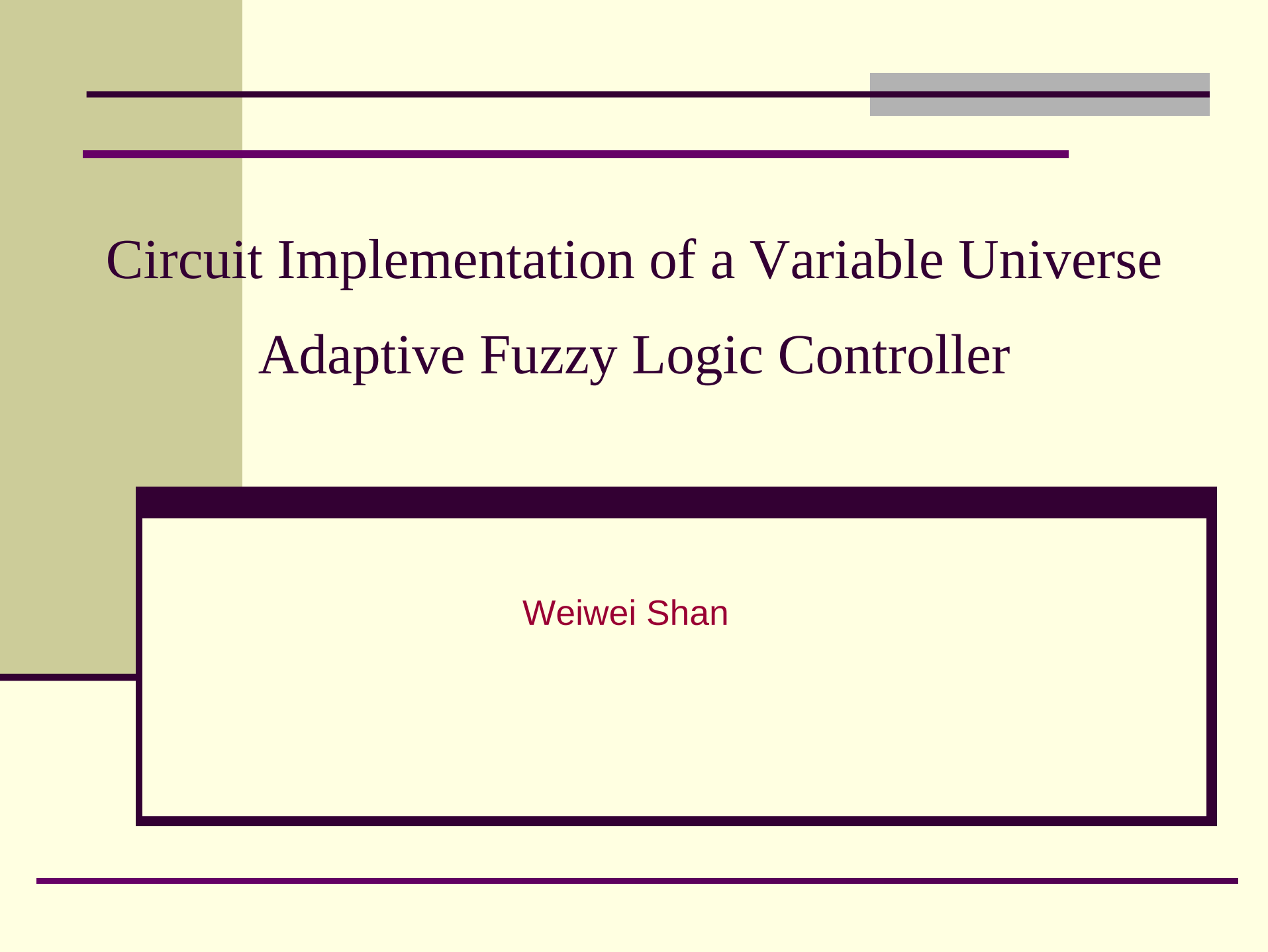




Circuit Implementation of a Variable Universe Adaptive Fuzzy Logic Controller

Weiwei Shan

Outline

1. **Introduction: Fuzzy logic and Fuzzy control**
2. **Basic Ideas of Variable Universe of Discourse**
3. **Algorithm and Construction of VFLC**
4. **Analog circuit design**
5. **Conclusions**

1. Introduction Fuzzy Logic

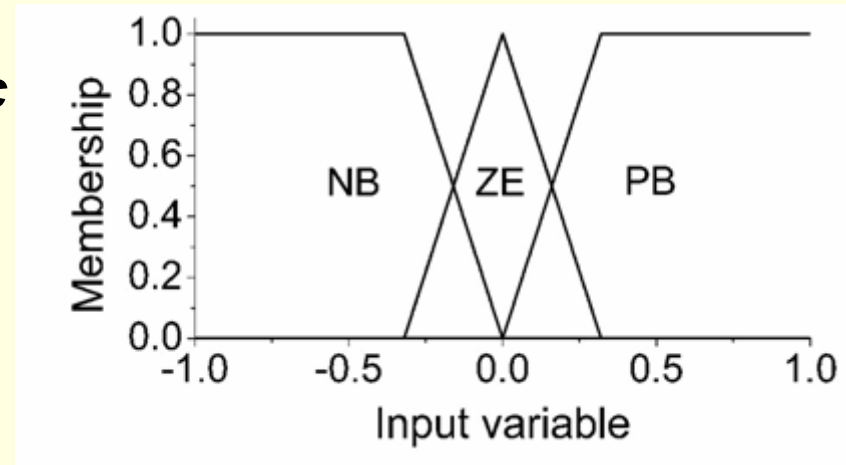
- Zadeh: Fuzzy sets theory, 1965
- Mamdani: Fuzzy control in engine, 1974
- Applications:
 - Automobile, Home appliances such as Washing machine, AC
 - Process Control, Signal processing, Pattern recognition, fuzzy optimization
- **Fuzzy logic:** derived from Fuzzy sets theory, dealing with reasoning that is approximate rather than precisely deduced from classical logic.
- Fuzzy logic control:
 - Nonlinear control
 - No need of exact mathematical model
 - Can utilize expert's knowledge

■ Fuzzy set,

- for all the **crisp variable** x of the Universe of Discourse U , for a set A belonging to U , $A = \{x | u(x)\}$ is a **fuzzy set**.
- $u(x)$: Membership function.
- $u(x) = \{0, 1\}$ – **Crisp logic**
- $u(x)$ between $(0, 1)$ – **fuzzy logic**

$$\mu_{\tilde{A}} : X \rightarrow [0, 1]$$

$$\mu_{\tilde{A}}(x) = \text{degree of } x \text{ in } \tilde{A}$$

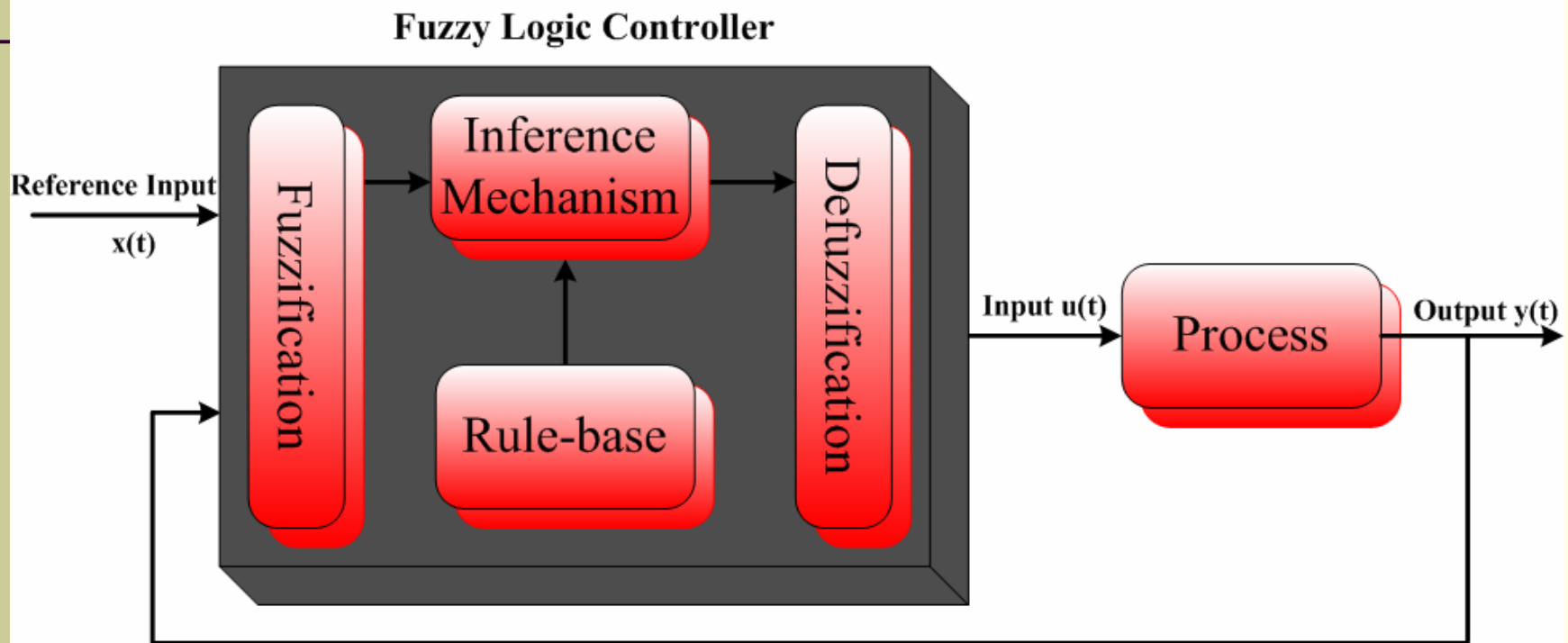


Fuzzy IF/THEN rules

- IF *variable IS set* THEN *action*
- Eg, a simple temperature regulator using a fan
 - IF temperature IS cold THEN turn down fan
 - IF temperature IS normal THEN maintain level
 - IF temperature IS hot THEN speed up fan

Control quantity		e		
		NB	PB	ZO
ec	NB	-3	0	-3
	ZO	-2	2	0
	PB	0	3	3

Fuzzy logic controller



Fuzzy Inference: TS-model

"If x is A , Then $y=f(x)$ "

Defuzzification: Center of Area

$$F(x_1, x_2) = \frac{\sum_{i=1}^n (A_i(x_1) \wedge B_i(x_2)) \cdot y_i}{\sum_{i=1}^n A_i(x_1) \wedge B_i(x_2)}$$

2. Basic Ideas of Variable UOD

■ Why adaptive?

- Any practical systems have some kinds of uncertainty
- When there are not enough control rules, the required control effect cannot be guaranteed.
- The number of fuzzy rules increases exponentially with the number of fuzzy partitions

■ Why hardware implementation?

- High speed, suitable for real-time control problems
- Parallel processing

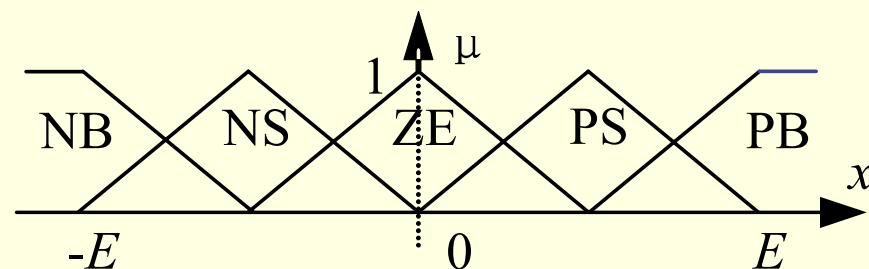
■ How? Some researchers:

- Make the fuzzy rules adaptive, a lot of parameters
-

H.-X. Li: Variable Universe FLC

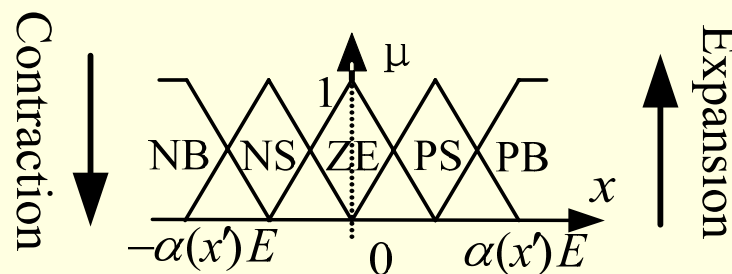
■ Features

- Adding only a few input and output factors
- Proved stability
- Fine control: Successfully controlled a quadruple inverted pendulum.



(a) Original Universe of Discourse and fuzzy partitions

- Universe of input and output variables can respectively change along with the changing of input variables.



(b) Contracted Universe of Discourse

- A smaller input leads to a smaller UOD, acting as if the partition of the UOD is more refined.

Algorithm

- Zero-order T-S model For the conventional FLC.

- $X_i = [-E_i, E_i]$ ($i=1,2$), input universe
- $Y = [-U, U]$, output universe

- Fuzzy inference rules

If x_1 is A_{1j} and x_2 is A_{2j} then y is y_j , $j=1,2,\dots,m$.

- The variation of UOD can be denoted as:

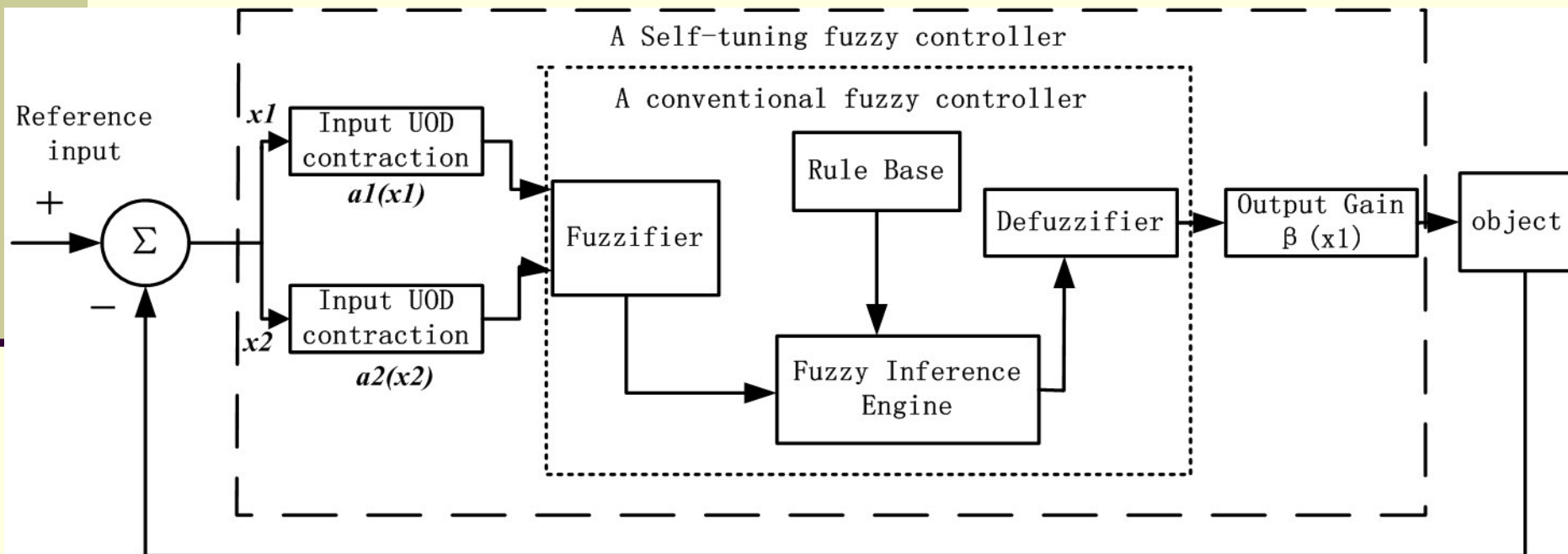
$$X_i(x_i) = [-\alpha_i(x_i)E_i, \alpha_i(x_i)E_i], \quad Y(y) = [-\beta(\underline{x})U, \beta(\underline{x})U]$$

- The output of the variable FLC is deduced as:

$$y = \beta(\underline{x}) \sum_{j=1}^m A_{1j} \left(\frac{x_1}{\alpha_2(x_1)} \right) A_{2j} \left(\frac{x_2}{\alpha_2(x_2)} \right) y_j$$

3. Construction of the FLC

- A conventional FLC
- A contraction factor before each input
- A self-tuning output gain factor after the output



■ The contraction factors of input UOD

- A formula suggested by H.-X. Li:

$$\alpha(x) = 1 - \lambda \exp(-kx^2), \quad \lambda > 0, \quad k > 0$$

■ The output tuning factor

$$\beta(t) = \int_0^t k_I \underline{e}^T P_n d\tau + \beta(0).$$

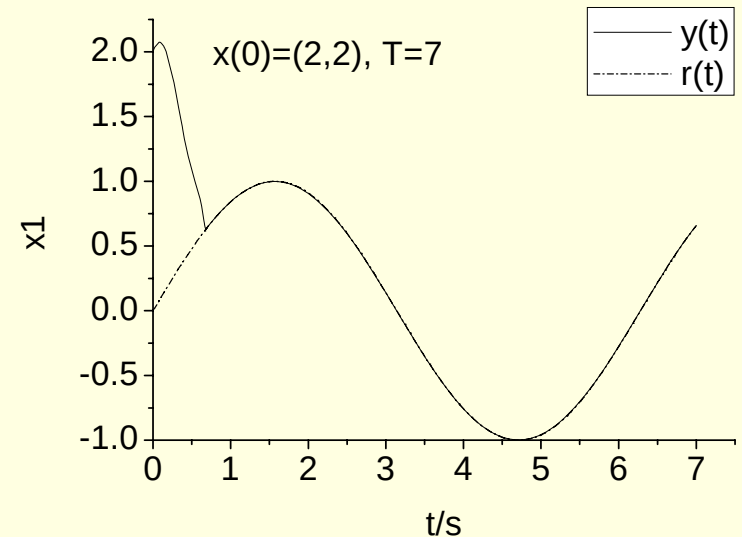
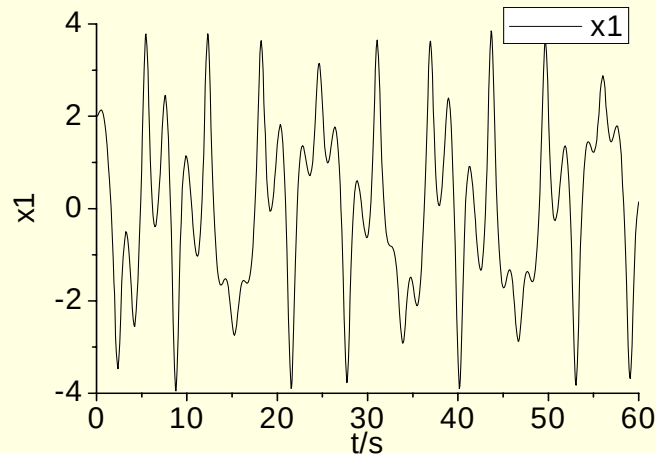
- Most of the control objectives are to control the input variable (error) to zero.
- by means of the integral regulation, may eliminate the static error.

An example

- A second order chaotic system: Duffing forced oscillation system
- To force the output state x_1 quickly track a reference signal

$$\dot{x}_1 = x_2,$$

$$\dot{x}_2 = -0.1x_2 - x_1^3 + 12\cos t + u(t).$$



- Output state x_1 without control

After VFLC control

4. Analog circuit design

■ Conventional FLC

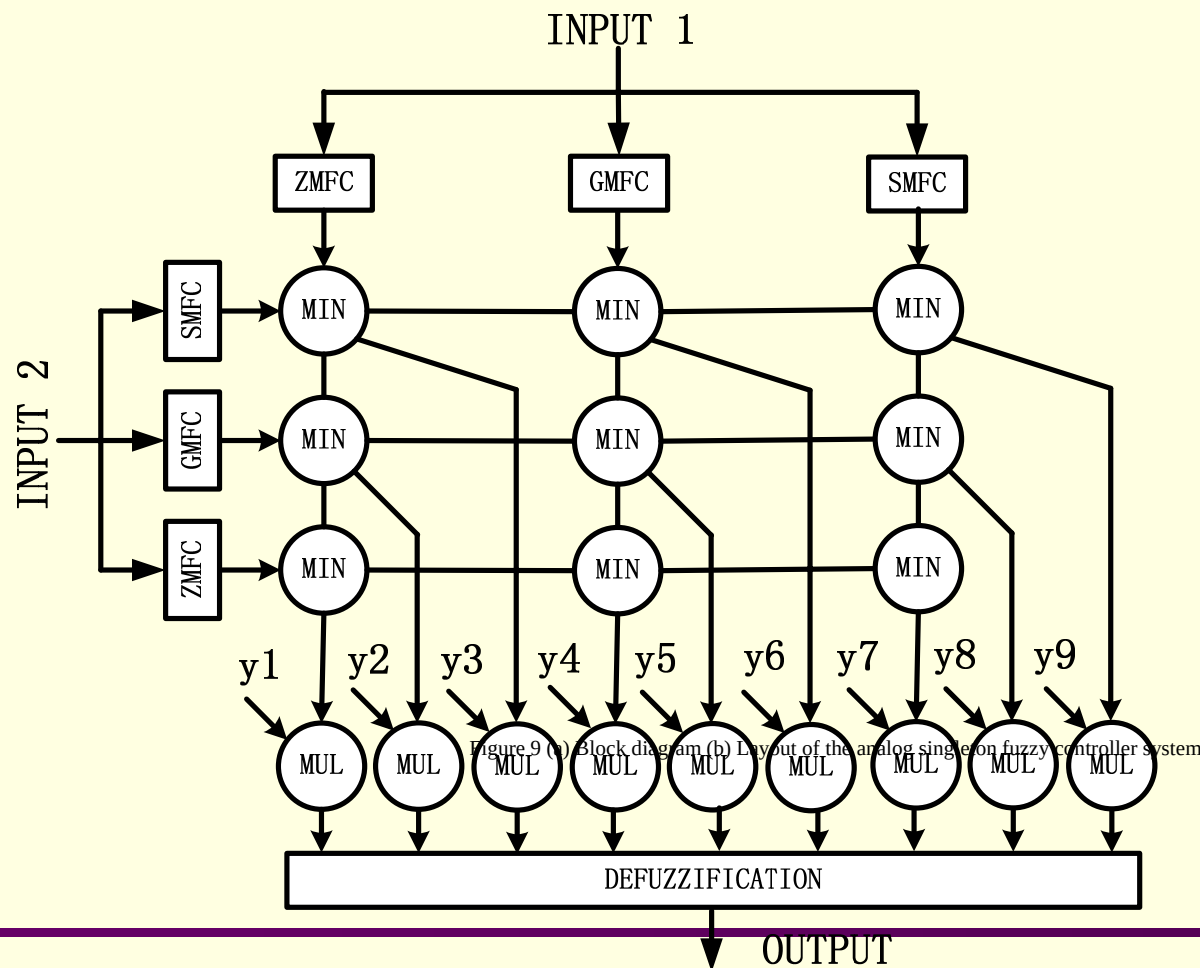
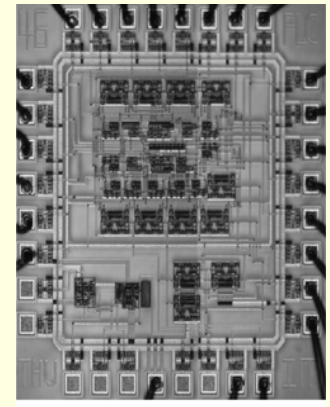
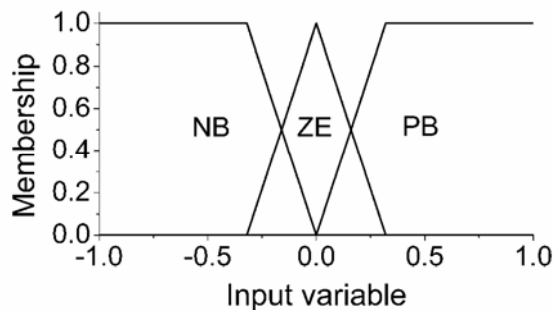


Figure 9 (a) Block diagram (b) Layout of the analog singleton fuzzy controller system

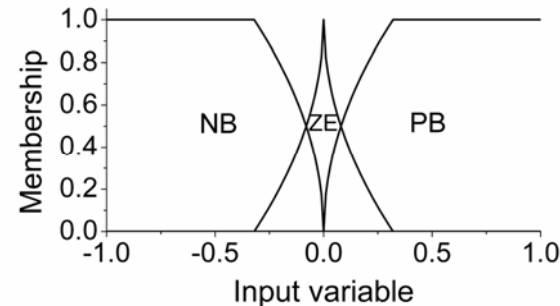


■ Input contraction factor

- Only need to function around 0
- Output tuning factor more important
- $A(x/\alpha(x))$ Peaky-triangle membership function

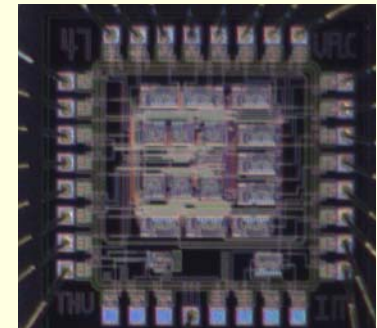
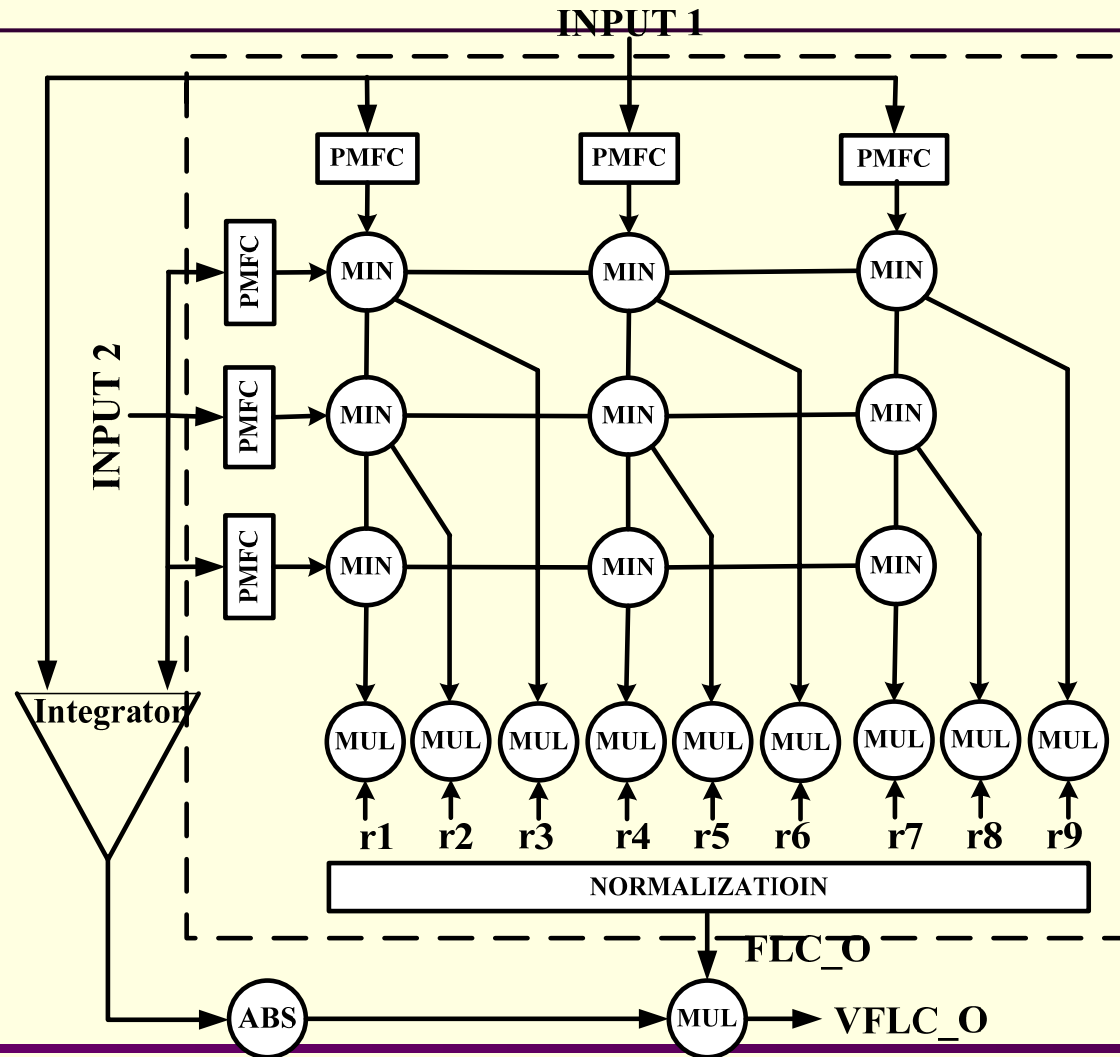


(a) The original MF



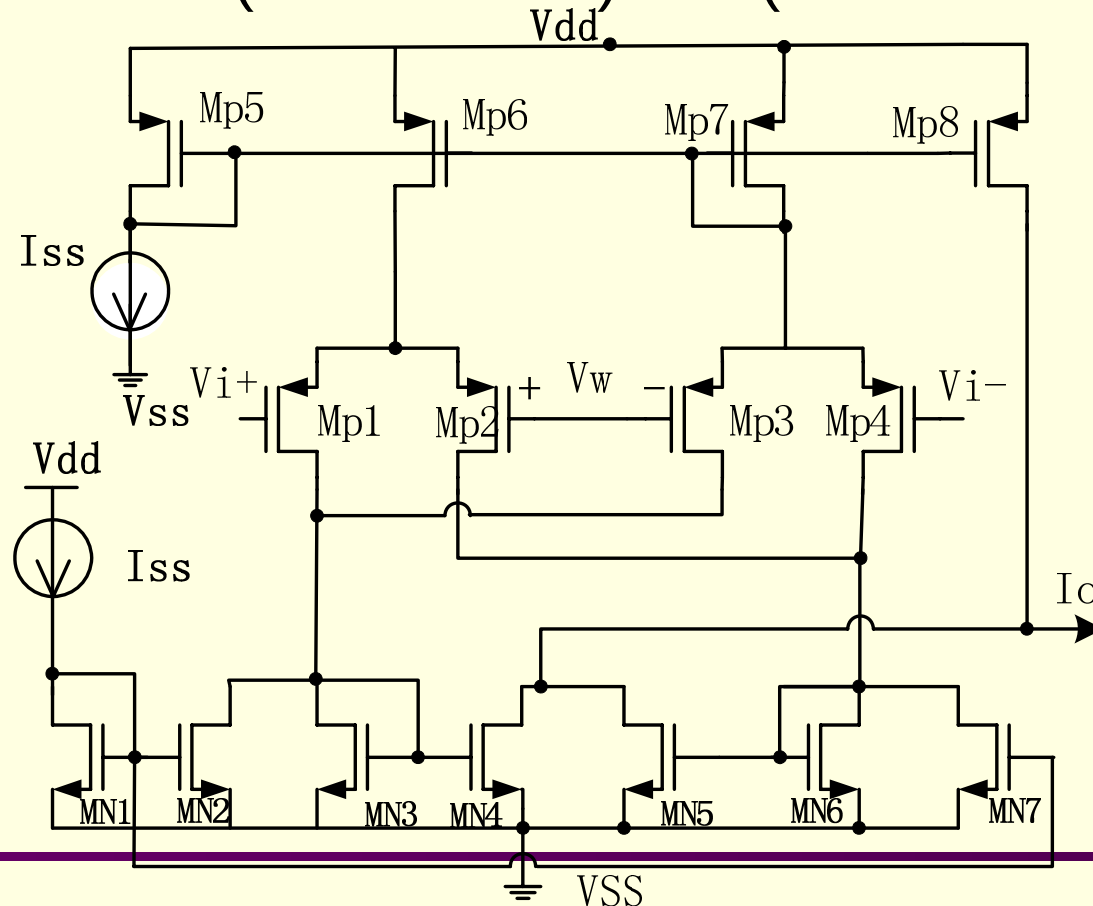
(b) The transformed MF $A(x/\alpha(x))$

VFLC system architecture



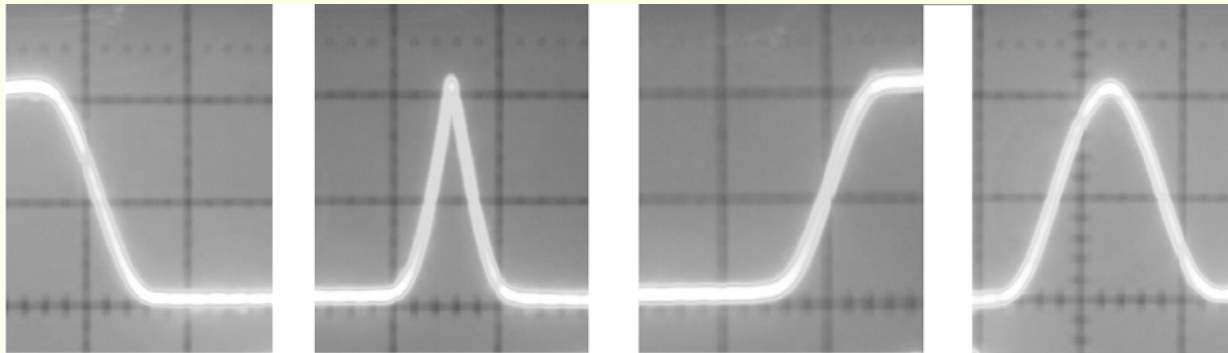
Input Membership Function Circuit

- differential pairs
- $I_{out} = I_{MP8} - (I_{MN4} + I_{MN5}) = I_{SS} - (I_{MN3} + I_{MN6})$



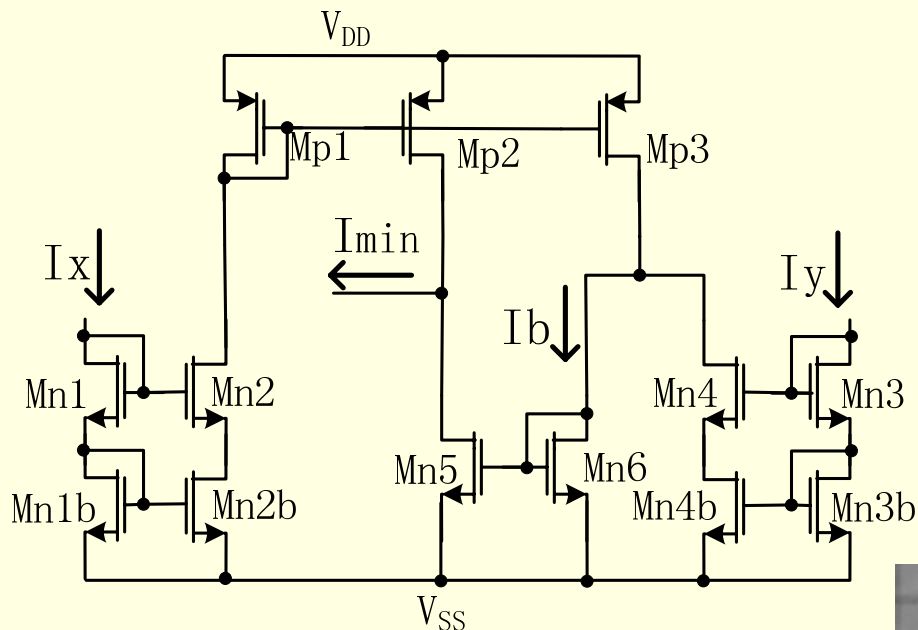
Test results

- $V_{w+}=V_{w-}=0V$, peaky-triangle
- $V_w = 0.3V$, Gaussian-like MF
- $V_w = 0.5V$, trapezoidal MF, shifting to left or right, get Z-shape MF or S-shape MF



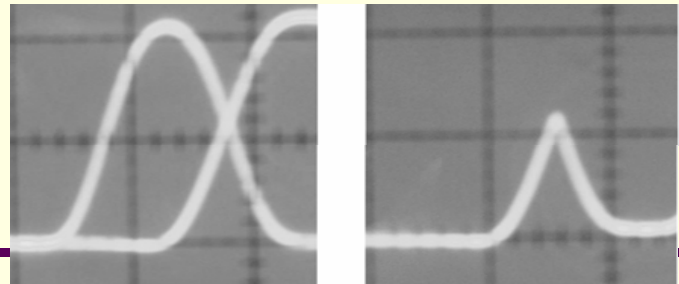
Inference circuit (Minimization Circuit)

- Current-mode minimization circuit according to the bounded-difference equations



$$I_b = \begin{cases} I_x - I_y, & I_x \geq I_y \\ 0, & I_x < I_y \end{cases}$$

$$I_{\min} = I_x - I_b = \begin{cases} I_y, & I_x \geq I_y \\ I_x, & I_x < I_y \end{cases}$$



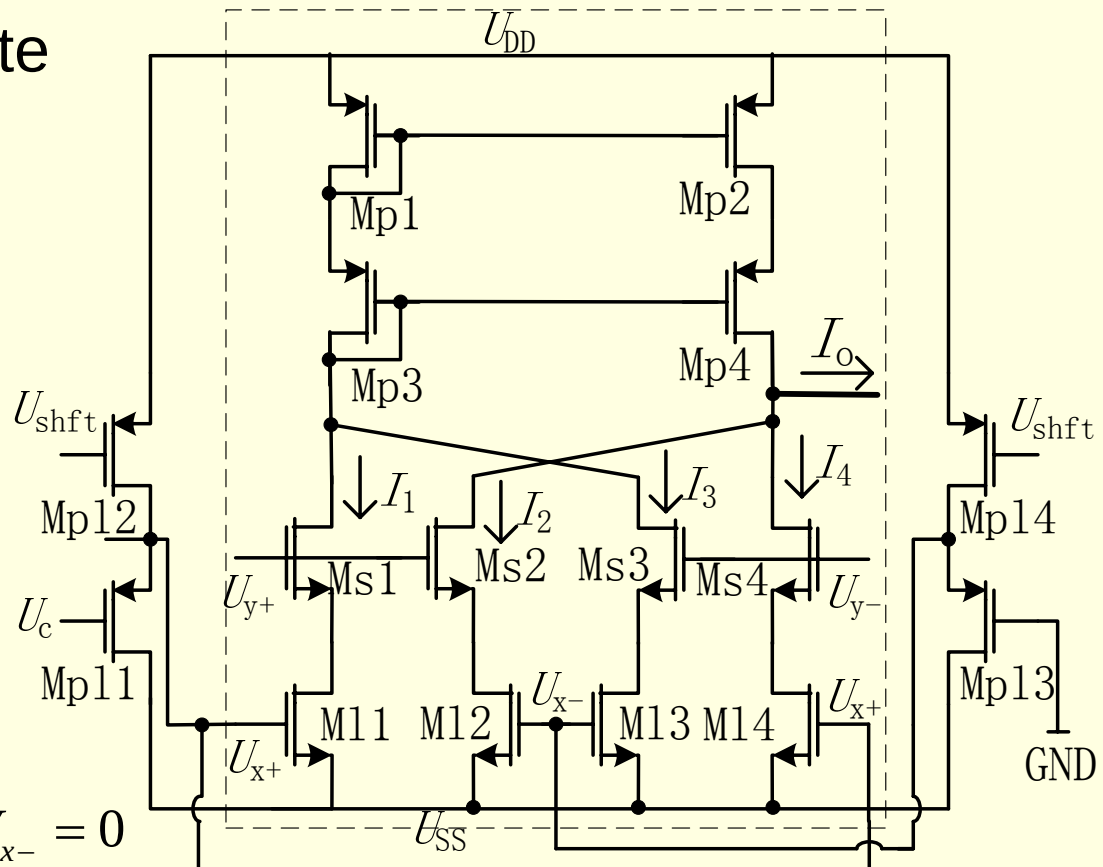
Multiplier and defuzzification circuit

- voltage mode four-quadrant multiplier
- Ms1~Ms4: saturate
- Ml1~Ml4: linear

$$I_o = (I_1 - I_2) + (I_3 - I_4)$$

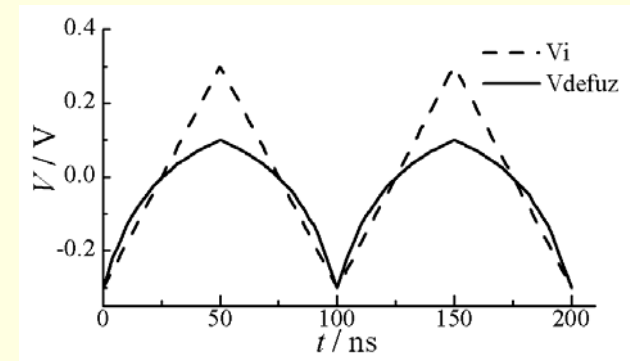
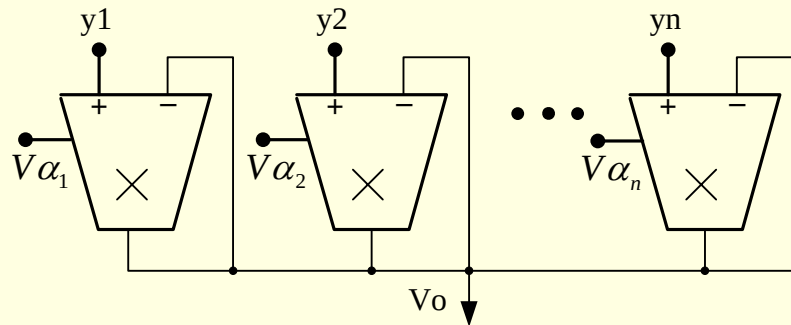
$$= K \cdot (V_{x+} - V_{x-}) \cdot (V_{y+} - V_{y-})$$

$$I_o = K \cdot V_{x+} \cdot (V_{y+} - V_{y-}), \text{ when } V_{x-} = 0$$

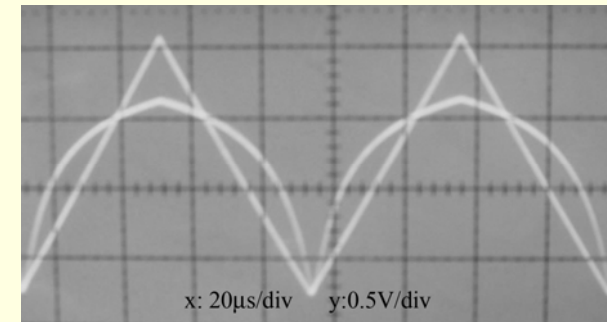


Defuz

■ Defuzzification circuit

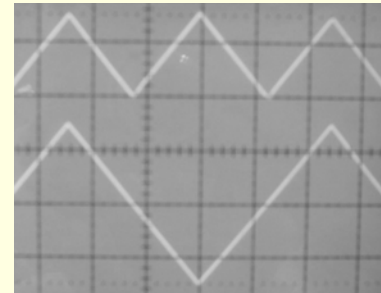
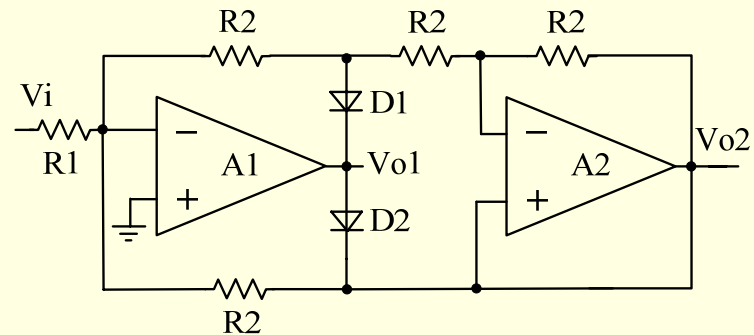
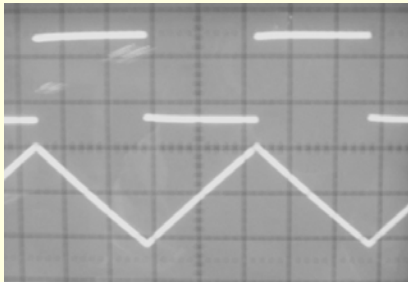
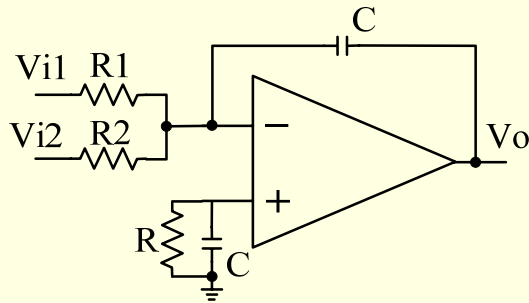


$$\sum_{i=1}^n Kc_i (y_i - V_o) = 0 \Rightarrow V_o = \frac{\sum_{i=1}^n c_i y_i}{\sum_{i=1}^n c_i}$$

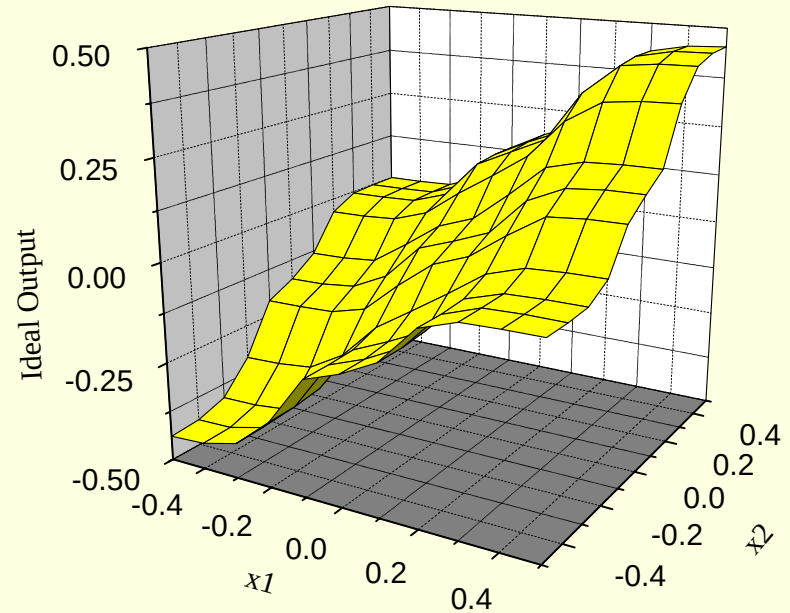
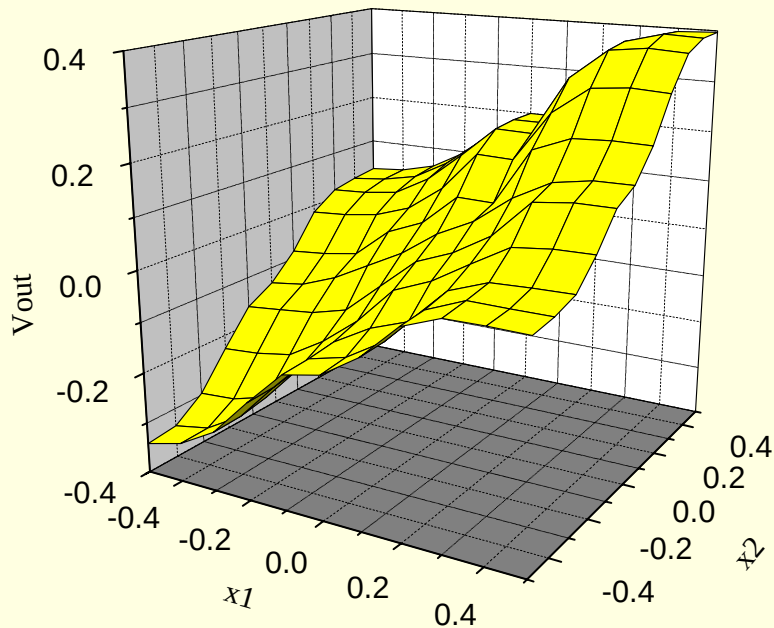


Output universe contract factor

- an integrator and an absolute circuit



Static test result of the inner FLC



5. Conclusions

- Improved FLC structure
 - This FLC is constructed with input UOD contraction factors and output gain factor. All of the factors are adjusted with input variables.
- Analog circuit implementation
 - Much higher speed than software, can be used for real-time control

Thank you!

Questions
