Abstract—The cell of cellular neural network (CNN) studied in this work is realized by negative differential resistance (NDR) devices. The NDR device is composed of metal-oxide semiconductor field-effect transistor (MOS) devices. Therefore, we can fabricate the cellular neural network by standard CMOS or BiCMOS process.

I. INTRODUCTION

The cellular neural network were invented by Chua and Yang in 1988[1,2,3]. It is in order to solve real-world problems in image processing, robotics, motion video and many other complex computational problems. The definition of cellular neural network is n-dimensional array of mainly identical dynamical systems, called cells, which satisfies two properties: most interactions are local with a finite radius r, and all state variables are continuous valued signals. The circuit of basic cell \( c(i, j) \) is shown in figure 1.

\[
I_{xu}(i, j; k, l) = B(i, j; k, l)V_{ukl}\quad . \quad \quad (2)
\]

\[
I_{xy} = \frac{1}{2}R_s\left(\left|V_{xij} + 1\right| - \left|V_{xij} - 1\right|\right) \quad \quad (3)
\]

is a piecewise-linear voltage controlled current source; \( E_{ij} \) is a time-invariant independent voltage source. The circuit equations of a cell which satisfy KCL and KVL are easily derived as follow: State equation is

\[
C\frac{dV_{xij}(t)}{dt} = -\frac{1}{R_s}V_{xij}(t) 
\]

\[
+ \sum_{C(k,j)\in N(i,j)} A(i, j; k, l)V_{ykl}(t) 
\]

\[
+ \sum_{C(k,j)\in N(i,j)} B(i, j; k, l)V_{ukl}(t) + I. 
\]

Where \( A(i, j; k, l) \) and \( B(i, j; k, l) \) are the nonlinear cloning templates. Output equation is

\[
V_{yij}(t) = \frac{1}{2} \left(\left|V_{xij}(t) + 1\right| - \left|V_{xij}(t) - 1\right|\right). \quad \quad (5)
\]

Input equation is

\[
V_{uij} = E_{ij}. \quad \quad (6)
\]

Constraint conditions are

\[
\left|V_{xij}(0)\right| \leq 1, \left|V_{uij}\right| \leq 1. \quad \quad (7)
\]

Parameter assumptions are

\[
A(i, j; k, l) = A(k, l; i, j), \quad \quad (8)
\]

where \( 1 \leq (i, k) \leq M, 1 \leq (j, l) \leq N \) and \( N(i, j) \) is the neighbor set of \( C(i, j) \).

II. NEGATIVE-DIFFERENTIAL RESISTANCE DEVICE OF METAL-OXIDE-SEMICONDUCTOR (MOS) FIELD TRANSISTORS

The MOS-NDR device[4,5] consists of the metal–oxide–semiconductor field-effect transistors (MOS). A MOS-NDR device is composed of three n-channel MOS, and one p-channel MOS. Transistor m1 acts as a load resistor with the gate shorted to the drain, which is used to modulate the input gate voltage of transistor m3, and transistor m2 behaves as an active switch with the gate electrode connected to the gate of driver transistor m3 and the drain electrode of driver transistor mp4. The substrate of load transistor m1, the substrate and source of transistor m2, the source of transistor m3 which are connected together with the gate and source of transistor mp4. The circuit representation of the
MOS-NDR device is shown in figure 2.

![MOS-NDR device circuit](image)

Fig. 2. A N-type NDR device circuit is composed of three NMOS and one PMOS.

The output characteristics of the MOS-NDR device simulated by HSPICE program are shown in figure 3. For simplifying the analysis, the output characteristic of the MOS-NDR device is divided into three regions. The region I is called as first positive resistance region. In this region, transistor mn2 is off, transistor mn1 is kept in saturation, transistor mn3 is in linear state and transistor mp4 is off. Therefore, the first positive resistance region is according to I-V characteristic of mn3. When \( V_{dd} > V_{r2} \), transistor mn2 is on and will change its state from linear to saturation. Transistor mn3 will change its state from linear to off. Transistor mp4 will turn on. We call it as negative differential resistance region. When mn3 change its state from linear to off, it happens very quickly. Sometimes, it is called as the quenching. But transistor mp4 turn on slowly. This is why the electric current will change suddenly. As \( V_{dd} \) increasing, transistor mp4 is saturation, transistor mn2 is in linear state and transistor mn3 is off. We call it as second positive resistance region.

![I-V characteristic curve](image)

Fig. 3. The I-V characteristic of MOS-NDR device.

III. CNN’S CELL BASED ON NDR DEVICE

In this section, the cell of CNN using MOS-NDR devices is proposed. The schematic circuit and I-V curves are shown in figure 4. The outputs of cell are determined by \( V_{in} \) and \( V_{data} \) according to the MOBILE (monostable-bistable transition logic elements) theory [6]. When \( V_{in} \) is in high state, \( V_{out} \) will be in low state whether the value of \( V_{data} \). When \( V_{in} \) is in low state and \( V_{data} \) is in high state, \( V_{out} \) is in high state.

![Schematic circuit of MOS-NDR-based CNN’s cell](image)

Fig. 4(a). It is the schematic circuit of MOS-NDR-based CNN’s cell.

![I-V characteristic curve of MOS-NDR-based CNN’s cell](image)

Fig. 4(b). It is the I-V characteristic curve of MOS-NDR-based CNN’s cell.

![CNN's cell schematic](image)

Fig. 4(c). When \( V_{in} \) is high, \( V_{out} \) is low, e.g. point A and B, whether the value of \( V_{data} \). When \( V_{in} \) is low and \( V_{data} \) is high, \( V_{out} \) is high, e.g. point C.

We use this MOS-NDR-based CNN’s cell to compose of a 3×3 CNN. It is shown in figure 5. The cloning templates are

\[
B = \begin{bmatrix}
  V1 & V2 & V3 \\
  V4 & V5 & V6 \\
  V7 & V8 & V9 \\
\end{bmatrix} = \begin{bmatrix}
  0 & 1.5 & 0 \\
  1.5 & V5 & 1.5 \\
  0 & 1.5 & 0 \\
\end{bmatrix},
\]

(9)

I=1,

and

\[
V5 = \text{sign}\{5 \cdot V5 - 1.5(V2 + V4 + V6 + V8)\} + 1.
\]

(10)

![3x3 cellular neural network](image)

Fig. 5. A 3x3 cellular neural network.
The simulating results are shown in figure 6. Widths of MOS transistors are equal to 15μm for V2,V4,V6, and V8 each other. Width of V5 is equal to 50μm, and width of I is equal to 10μm. We can get a stable output in a very short simulating time.

IV. CONCLUSION

The cellular neural network has many applications. It is a nonlinear network and has many interesting phenomena. The negative differential resistance devices are suitable for the performance of characteristics of cellular neural network. The resonant tunneling diode is the famous NDR device. But it is less flexible than the MOS-NDR device. The MOS-NDR device can easily be modulated by width and gate voltage of MOS transistor. We have proposed cells of cellular neural network which are composed of MOS transistors and a 3×3 network has been constructed. This 3×3 network gives a good result. We have studied N×N network for N is large than 25 numerically, but haven’t realized by MOS-NDR devices yet. We will continuously study MOS-NDR-based N×N cellular neural network and realize the integral circuit of MOS-NDR-based CNN.

REFERENCES
