works for the first, and last, several stages. The problem is not present in the pulse delay line because the gain per stage in that case never exceeds unity at any frequency.

The delay line circuits were fabricated in 2μm MOSIS CMOS double-polysilicon technology, with a 20-stage delay line occupying 1100 μm × 2100μm² and dissipating 45mW per stage.

Potential applications for radar or adaptive antenna systems: A potential radar application of the tapped delay line is as a fine time resolution programmable delay line for a moving target indicator clutter canceller when used in conjunction with a component for achieving long delays, such as surface acoustic wave delay line devices [3]. Another candidate application of the delay line is to implement transversal filters to match amplitude and phase over the operating band at the outputs of auxiliary channels of an adaptive sidelobe canceller [3].

The tapped delay line could also potentially be implemented along with an integrated LMS adaptive processor to improve the bandwidth performance of linear adaptive antenna arrays. Improved bandwidth performance of an adaptive array can be obtained with as few as three quarter-wave delay elements behind each antenna element [4, 5].

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Simplified scheme for realisation of Chua oscillator by using SC-CNN cells

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Indexing terms: Cellular neural nets, Chaos, Chua's circuit

A new simplified scheme for the Chua oscillator, realised by using a state controlled cellular neural network (SC-CNN), is reported. The number of operational amplifiers (opamps) for the introduced implementation has been greatly reduced with respect to previous realisations. Experimental and simulation results are included to show the suitability of the considered configuration.

Introduction: Owing to several attractive dynamical properties of cellular neural network (CNN) systems [1], many studies have been carried out in the generation of complex dynamics by using this paradigm. Moreover, spatial arrays based on Chua oscillators have recently been proposed [2 – 4].

A new scheme of CNN, called state controlled cellular neural networks (SC-CNNs), has also recently been introduced by the authors [5] together with a new type of Chua oscillator [2] realisation. Therefore a Chua oscillator array can be generated as a suitable SC-CNN cells array. From here, the necessity arises for simplifying the SC-CNN realisation as much as possible, to reduce the complexity of the whole array.

An implementation of a SC-CNN based Chua oscillator with eight opamps has previously been proposed by the authors [5]. In this Letter, a simplified scheme, including only four opamps, is given; the circuit is described and both simulation and experimental results are included.

SC-CNN model: Chua and Yang [1] defined the so-called linear CNN model in which the state variable of each cell directly depends on the outputs and inputs of the neighbouring cells. In the new model, the direct dependence on the state variables of the neighbours is introduced. Therefore, in accordance with the classical CNN symbolism, the SC-CNN is defined as follows:

Definition: The state controlled cellular neural network (SC-CNN) is an array of nonlinear circuits $C(j)$ with the following state equations:

$$\dot{x}_j = -x_j + \sum_{C(k)\in N(j)} A_{j;k} y_k + \sum_{C(k)\in N(j)} B_{j;k} u_k + \sum_{C(k)\in N(j)} C_{j;k} x_k + I$$
$$y_j = f(x_j) \qquad 1 \le j \le N \tag{1}$$

where

$$f(x) = \frac{1}{2}(|x+1| - |x-1|) \tag{2}$$

where x_j, y_j, and u_j are the state variable, and output and input of the cell $C(j)$, N is the number of cells, $N(j)$ is the neighbour set of the cell $C(j)$, f is the output nonlinearity function and I is the bias. Moreover, $A_{j;k}$, $B_{j;k}$ and $C_{j;k}$ are real constants named feedback template, control template and state template, respectively.

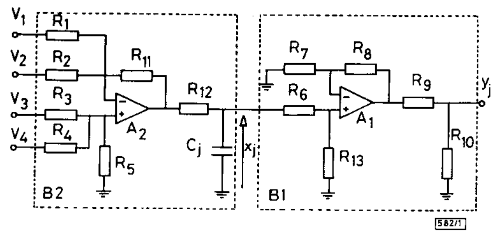

Fig. 1 *Simplified SC-CNN cell scheme*

Improved cell realisation for SC-CNN based Chua oscillator: The SC-CNN based Chua oscillator was previously realised by using three cells [5]. Each cell was implemented with a discrete component circuit by using three opamps [5]. The simplification of the original cell circuit comes from a very easy observation: the noninverting amplifier block could be avoided if an algebraic summing amplifier, that includes the inverting operation, is introduced. Therefore, a simplified circuit realisation with only two opamps for each cell is now presented and its scheme is shown in Fig. 1. The circuit consists of two blocks: the block B1 realising the nonlinear function of eqn. 2 and the block B2 that constitutes the cell core. The block B1 is actually a differential amplifier stage followed by a resistive voltage divider. It realises the nonlinearity of eqn. 2 by exploiting the natural saturation of the amplifier itself; therefore it has to be designed so that the amplifier output saturates when the input voltage reaches the desired breakpoints (i.e. when $|x_j| > 1$). The voltage divider attenuates the amplifier output to match the correct signal level.a

The block B2 realises the actual cell core and is constituted by an algebraic summing amplifier stage followed by an RC network. If the input impedance of the block B1 (i.e. R_6) is very high compared to the output impedance of the block B2 (that is, $R_{12}/(1 + j\omega C_j R_{12})$) then the block B1 does not sensibly influence the capacitor voltage and the following state equation holds:

$$C_j \dot{x}_j = -\frac{1}{R_{12}} x_j + \frac{R_{11}}{R_1 R_{12}} V_1 + \frac{R_{11}}{R_2 R_{12}} V_2 - \frac{R_{11}}{R_3 R_{12}} V_3 - \frac{R_{11}}{R_4 R_{12}} V_4 \tag{3}$$

where V_1 and V_2 are the noninverting inputs and V_3 and V_4 are the inverting inputs. Finally, R_5 is used for the offset compensation and has to be chosen as

$$\frac{1}{R_5} = \frac{1}{R_{11}} + \frac{1}{R_1} + \frac{1}{R_2} - \frac{1}{R_3} - \frac{1}{R_4} \qquad (4)$$

Of course, this circuit is easily generalised for an arbitrary number of inverting/noninverting inputs; it can be readily verified that eqn. 1 and eqn. 3 are formally equivalent.

In this way, the noninverting inputs will be used to realise the terms associated with positive template coefficients, whereas the inverting inputs will be used to realise the negative template terms.

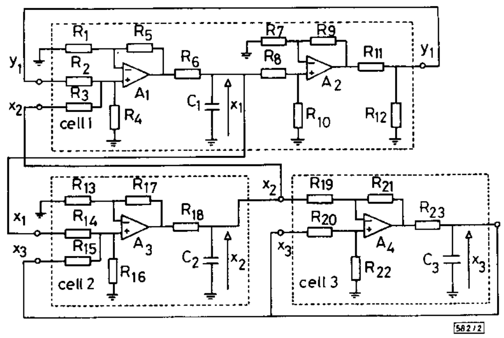

Fig. 2 *Complete circuit scheme*

Complete circuit scheme: In the Chua oscillator case, as shown in a recent paper [5], three cells are needed (one for each state variable). In [5], an eight-opamp realisation was reported, whereas, with the new cell circuit, only four opamps are needed. In fact, whereas the first cell circuit consists of the presented complete two-opamp scheme, the second and third cells do not need the nonlinear blocks and thus contribute with only two additional opamps realising their cell cores. The complete four-opamp Chua oscillator is shown in Fig. 2, whereas the corresponding part list is shown below. From the above discussion, the detailed circuit design is straightforward and it is no reported for shortness.

The simulated and experimentally observed phase portrait in the x_3-x_2 plane, referring to the case of the well-known double scroll attractor [2, 5], are shown in Fig. 3 and Fig. 4, respectively.

Part list:

Cell 1: R_1 = 4kΩ, R_2 = 13.2kΩ, R_3 = 5.7kΩ, R_4 = 20kΩ, R_5 = 20kΩ, R_6 = 1kΩ, R_7 = 75kΩ, R_8 = 75kΩ, R_9 = 1MΩ, R_{10} = 1MΩ, R_{11} = 12.1kΩ, R_{12} = 1kΩ, C_1 = 100nF;

Cell 2: R_{13} = 51.1kΩ, R_{14} = 100kΩ, R_{15} = 100kΩ, R_{16} = 100kΩ, R_{17} = 100kΩ, R_{18} = 1kΩ, C_2 = 100nF;

Cell 3: R_{19} = 8.2kΩ, R_{20} = 100kΩ, R_{21} = 100kΩ, R_{22} = 7.8kΩ, R_{23} = 1kΩ, C_3 = 100nF;
Power supply: V_{cc} = +15V, V_{ee} = −15V

A single quad opamp TL084 chip was used for the four required operational amplifiers.

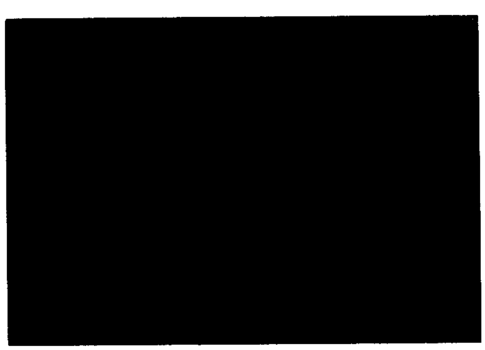

Fig. 4 *Observed phase portrait in x_3-x_2 plane*

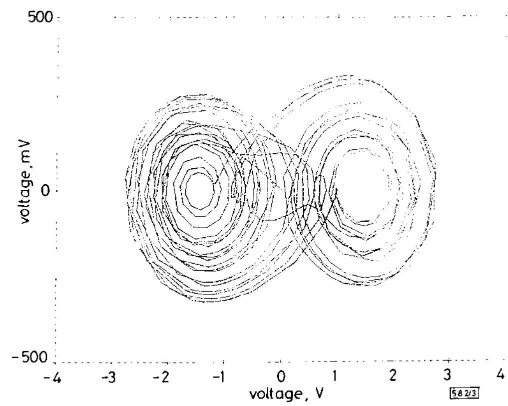

Fig. 3 *Simulated phase portrait in x_3-x_2 plane*

Conclusions: A simplified scheme of the Chua oscillator realised with SC-CNN cells has been presented. The suitability of the implementation has been proved to be in accordance with the simulation and experimental results. In this way, complex CNN circuit arrays based on Chua oscillators can easily be experimentally realised. Moreover, owing to the generality of SC-CNN approach for generating nonlinear dynamics, many other SC-CNN based realisations [5 – 7] can be significantly simplified in the same way.

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