Effective Design and Measurements of Switched Current Circuits

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Abstract: - Switched current circuits cover such important areas of application like filtering systems, neural networks, A/D and D/A conversion. In this paper very simple and effective design method and practical realization of switched current filters has been presented. Current mode circuits, because of their special structure, need appropriate methodology during design preparation. This paper is an overview of most common problems related with laboratory measurements of such circuits. Very efficient laboratory station for measurements of integrated circuits has been presented. The control computer permits to obtain in a simply way precision characteristics of current mode circuits.

Key-Words: - Integrated circuits, current mode circuits, switched current filters

1 Introduction

Switched current approach is an attractive signal processing method. Among main features deciding on the method attractiveness, the ability to operate at high frequencies or with low power supply is very important. Additional advantage is the simplicity of implementing various mathematical operations, such as summation, inversion and multiplication.

Additionally, the switched current circuits can be easily manufactured in standard CMOS technology. Owing to the above advantages the current mode techniques are commonly used in discrete-time analog signal processing, neural networks, A/D and D/A conversion [2, 3].

A big success of VHDL language for describing digital electronic systems permits to extend the top down methodology to analog circuits. A new standard of VHDL-AMS language is now available, but the top down design for analog systems, especially in the case of mixed components remains still very difficult in practice.

The proposed standardization of basic blocks and high quality performances of such blocks will permit to improve design efficiency of current mode systems.

2 Switched Current Filters

The most common structures used in current-mode circuits are current sources and current mirrors. In fact they are present in almost every analogue circuit and they are often only component of circuits. Quality of their design is a factor deciding of properties of the system consisting of such circuits. It is known that current mirrors are non-ideal elements, therefore simple static current mirrors, like presented in Fig. 1 are not suitable for high-quality processing. Their main drawback is a difference between drain-source voltages of input and output transistors caused by a drain-gate connection of input transistor [1]. It results in a difference between input and output current in spite of equal gate-source voltages. This non-ideality can be significantly reduced by using sophisticated mirrors like Wilson mirror, cascode mirror or regulated cascode mirror (Fig. 1ab) [1, 2].

Other way to avoid this problem is to use dynamic current mirrors. The problem of different drain-source voltages simply does not exist for such structure [1]. It is advantage of dynamic mirror in comparison with static mirror, but their is another effect causing non-ideal operation of both static and dynamic current mirrors. It is a swing of output transistor drain potential, which results in channel length modulation. It is caused by limited value of output impedance of current and behaviour of stage connected to such mirror's output, like next current mirror, which modifies output current of the mirror despite constant gate-source voltage. That effect can be also minimised by using sophisticated current mirrors in order to achieve very high value of theirs output impedance (Fig. 1ab).

The main idea of the paper is to design effective low power switched-current filters. The basic building block of the proposed filters contains an inverting integrator according to the schematic presented in Fig. 1c. A transfer function of such circuit is given by the following expression:

$$H(z) = \frac{i_{out}(z)}{i_{in}(z)} = -\frac{(a_5 + a_6)z^2 + (a_1 a_3 - a_5 - 2a_6)z + a_6}{(1 + a_4)z^2 + (a_2 a_3 - a_4 - 2)z + 1}$$

Afterwards, the designed building block has been used as biquadrat sections of the first filter (input $a_0 i_{in}$ and $a_6 i_{in}$) and as parallel second order sections of the second one (input $a_0 i_{in}$ and $a_5 i_{in}$). The regulated cascode [4] has been used in above structures to ensure high fidelity of current mirrors. Because the circuit has to be as small as possible, and to achieve reasonable clock feedthrough reduction, specially optimised switches containing CMOS transmission gates have been used [3].

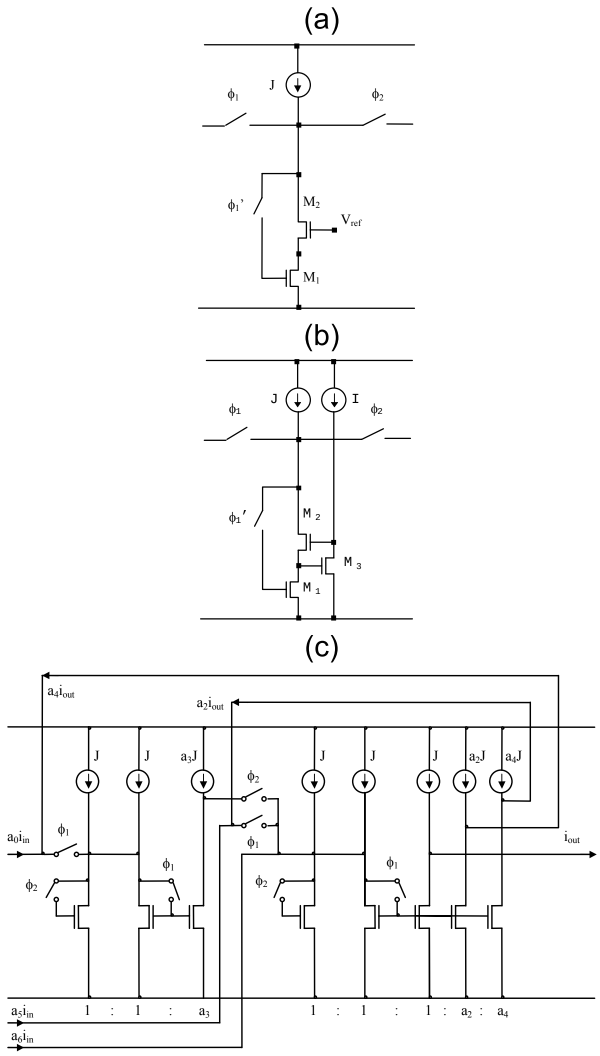

Fig. 1. Cascode dynamic current mirror (a), regulated cascode dynamic current mirror (b), and one section used in the filter realization (c)

To make design layout preparation easier and faster, special cells, including parameterised cells (see Fig. 2), have been created. These cells are in fact simple elements used in filters like current sources, current and memory switches, current summation points, power and signal buses etc.. Layout view of one filter containing biquadrat sections is presented in Fig. 3.

Another reason causing distortions in circuit functionality are process mismatches [4] causing an influence on parameters, like threshold voltage V_T, device aspect ratio and channel length modulation. The way to minimise these effects is special placing and routing of circuit components. Good results are achieved when similar components, like current mirror stages or current amplifier inputs and outputs, are placed in the same direction, and as close as possible to each other. The same direction causes similar mismatches of parameters for circuit components, like listed above, which allows keeping their functionality. Such approach is realised by using universal parameterised cells, consisting of a structure (presented in Fig. 3) which can be described as dynamic current copier without any switches.

Such cell can be used to create current copier and amplifier input-output stages, dynamic current mirrors, etc. Their structure forces such placing as described above. That kind of placement gives best results in application using current gain of integer numbers such as A/D and D/A converters [5]. In filtering applications current mirrors with arbitrary gain are usually used to implement coefficients of transfer functions.

In such cases the results of process mismatches are unavoidable. The solution is to use circuit structure which functionality is low sensitive to its deviations. Switched current circuits, applied to discrete-time processing, are interesting example of circuits, which functionality strongly depends of process mismatches. Their main drawback is a clock feedthrough effect. This disadvantage is minimised by using special structure of circuits. There are realisations using replica techniques, feedback, algorithmic processing etc [4, 6]. For all these solutions precision of transistors realisation is essential for proper work.

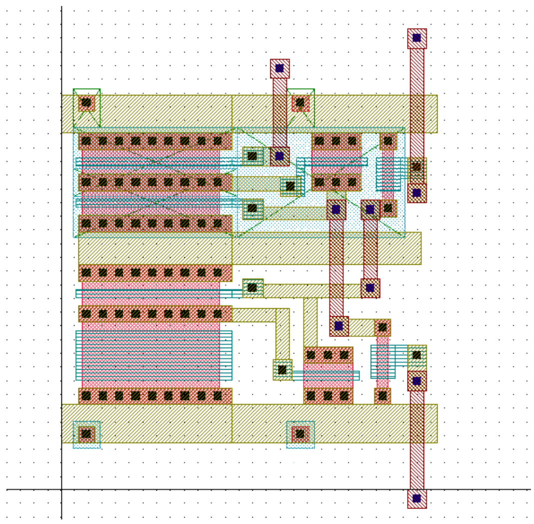

Fig. 2. Universal parameterised cell using regulated casdcode dynamic current mirror

As it was said, current mode circuits can work at low power supply but sometimes they consume a lot of the power. It is caused by big current values in VDD and VSS paths. For circuits consisting of great number of cascade connected stages these voltages can be significantly changed. Such situation can affect circuit functionality. The solution is to apply VDD/VSS voltages to power paths at several points of circuit and to use sufficiently wide VDD/VSS paths. Another effect related with circuits made of great number of cascaded stages is presence of current paths between distant circuit stages. This results in voltage fall along such connections. The problem can be solved by placing circuit's cascaded components not in straight line but „breaking" circuit and making a few rows. Therefore, the components placed originally very distant from each other become much closer. Furthermore sufficiently wide connection bars should be applied. This approach also conserve design area and problem of VDD/VSS voltages is not so important as previously.

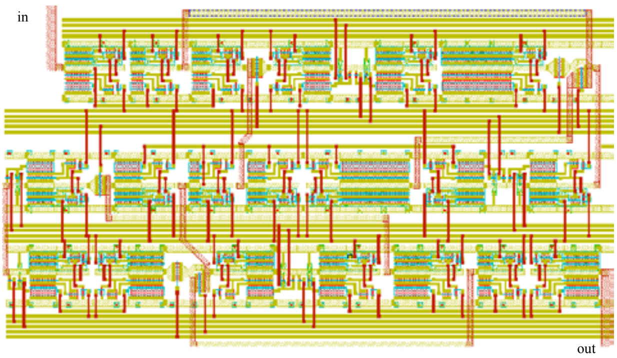

Fig. 3. Switched current CMOS VLSI filter, consisting of specially prepared cells

Filter design using current mode approach is related with one more difficulty. As it was pointed earlier, filter transfer function requires realisations of arbitrary value gains. It is impossible in practice, because every semiconductor technology have a limitation described as minimal size step.

Designer cannot use arbitrary transistor sizes and he is forced to use nearest valid values. Such operation modifies design properties and influence of this factor should be minimised. It can be achieved by using circuit structure which functionality is low sensitive to its deviations. Another possibility is to use bigger transistor - therefore current gains can be realised more accurately. One more way to avoid that problem is to use more advanced and expensive technology with small minimal step size.

3 Laboratory Measurements

LabVIEW itself is a software-only environment [7], but it is fully integrated for communication with hardware I/O instruments, such as rack-n-stack GPIB instruments, serial instruments via RS-232 and RS-485, VXI instruments (e.g. DAQ boards). The program can be also connected to data acquisition boards with and without signal conditioning, image acquisition systems, motion control systems and PXI/Compact PCI boards.

Owing to its driver's library and free online access for drivers, LabVIEW is also open for new hardware solutions.

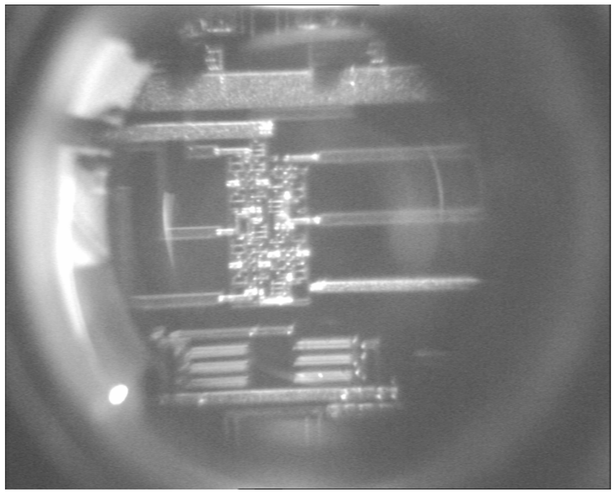

Fig. 4. Microphotograph of the switched current CMOS analog-to-digital converter

Nowadays, low-voltage technologies give new ideas how to design mixed circuits working in wide range of analog signals. Therefore, we have taken as an example CMOS realisation of modern A/D converters [5,].

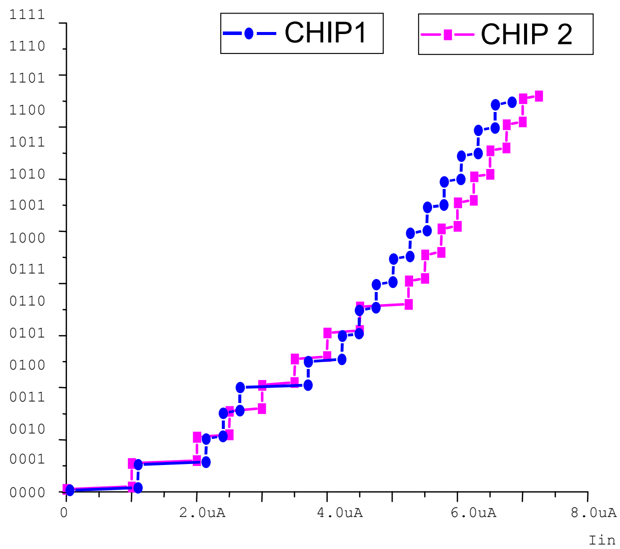

Fig. 5. Transient characteristics of the A/D converter measured for two chips

Fig. 4 shows the microphotograph of the converter fabricated in the CMOS technology. The results of laboratory measurements are presented in Fig. 5. We obtained slightly different characteristics for two different chips of the same 4-bit converter. LabVIEW environment is very helpful in measurement process. Additionally, it is possible to obtain graphic representation of the stored data in a simply way.

A switched-current circuit measuring position has been designed and realized for switched current integrated prototypes. Very specific structure of such circuits, which contains IIF filters and a set of function cells, required special interface card to be designed. In fact, mentioned interface card is central and the most important part of measuring position. Interface card works as a comprehensive measuring environment supplying examined circuits with sufficient set of steering signals and voltages, clock signals, and input-output management (Fig. 6).

Moreover, it provides access to voltages in most crucial points of card to enable remote measurements. Interface card has modular structure. It contains input-output connector section, measurement settings management section, input signal conversion section, output signal conversion section, input-output set choice section and clock signal set generation section. Although the interface card can be managed manually, it is equipped with EPP mode parallel port to enable automated control, e.g. using computer.

Designed interface card enables measurements of various current mode circuits. Such measurements may be performed because interface card has been fitted out with two rows of pin connectors which enable access to all resources of interface card. Unforeseen circuit can be connected to card via small daughter-board mounted on mentioned pin connectors. Similar pin connectors has been built-in into interface card to provide daughter board with EEP port.

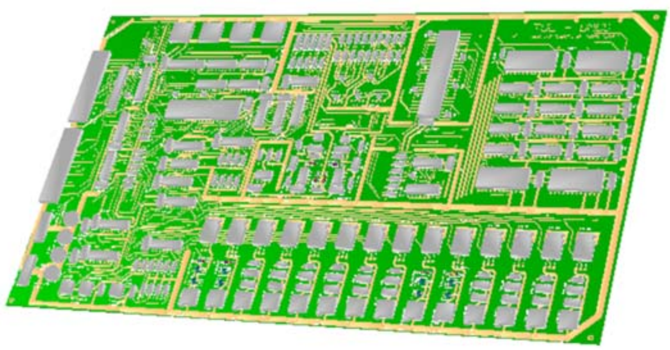

Fig. 6. A view of interface card

Basic set of measuring devices required to complete basic version of measuring position includes set of signal generators, voltmeter and oscilloscope. Of course user may feel free to develop more complex measuring position according to their needs. Usage of measurement devices equipped with control and data acquisition ports like serial port, parallel port and specially GPIG port gives opportunity to create automated measuring position, controlled and administered with computer. Implementation of software such as LabVIEW simplify such an operation and additionally provides tools for analysis, visualization and archiving of acquired measurement data. As a result user gets easy to use and efficient measuring position intended for current-mode integrated circuits including switch-current ones.

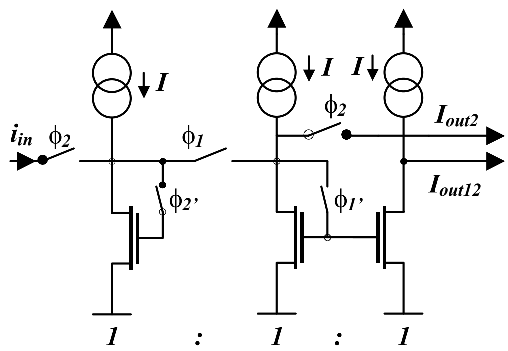

Fig. 7. Delay section of switched current filter

Currently, the preliminary tests of a laboratory stand containing this interface card, confirm high flexibility in precise measurements of CMOS current mode circuits. An example of switched current delay cell is shown in Fig. 7 [3]. The cell have been fabricated as one component of a CMOS integrated prototype (AMS 0.8μm technology) [3].

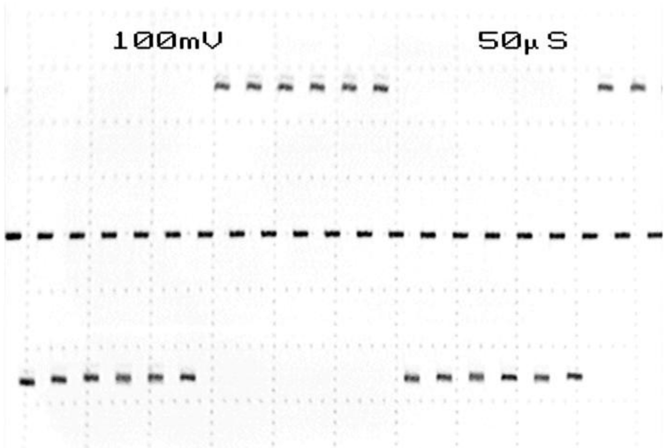

Fig.8. Output of the delay section

The laboratory measurement of the output *out2* is shown in Fig. 8. The input current (square wave excitation) and all clock signals have been produced using our interface card. The card contains also the current-voltage converter, therefore we can register output current as a voltage signal.

4 Conclusions

Two important problems have been discussed and solved. First, how to design efficiently switched current filters, minimizing influences of parasitic effects. Therefore, we obtained high precision CMOS integrated filters with low sensitivity to technological mismatches. The second one, we have made a lot of laboratory measurements of current mode integrated circuits. The proposed laboratory stands permit to obtain accurate current measurements of switched current circuits. Flexible external clock systems extend possibilities in laboratory measurements of integrated prototypes for wide range of frequency and for different clock configurations.

All integrated prototypes mentioned in this paper have been designed in CADENCE environment and fabricated using EUROPRACTICE facilities.

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