

A 1.2 μ BiCMOS realization of a low power and offset-free Voltage/Frequency converter

M. Zhang and F. Rodes

IXL-ENSERB
351, cours de la Libération
33405 Talence
France

e-mail: zhang@ixl.u-bordeaux.fr

Abstract: In this article, a voltage/frequency converter with dynamic offset trimming is presented. This converter is simple in structure, good in accuracy and low in power consumption. It is realized in a 1.2 μ BiCMOS technology. The result of test shows that an offset reduction as smaller as 600 μ V can be obtained.

Introduction

A data converter is one of the widely used circuit in electronic systems. Different structures have been proposed and developed, each with its advantages (accuracy, speed, simplicity, linearity, tolerance, consumption...).

According to different applications, some advantages become more important than the others. For example, in a biotelemetry system, consumption and accuracy are the most important parameters, which comes from the fact that the power supply is usually limited and that input signal is very weak, in the same order of offset of operational amplifier (opamp). A converter with higher ratio of signal to noise and low power consumption is preferred. That is why a Voltage/Frequency (V/F) converter with integration is chosen for its simplicity of structure and better performance against noise, proved by theoretical analysis[1]. The only inconvenient in this converter is the influence of offset as in the others. This can be overcome by an offset trimming.

In the following presentation, after a brief description of the V/F converter and its modified structure with offset trimming, a 1.2 μ BiCMOS realization is presented. The results of test and discussions are followed.

Voltage/Frequency converter

The schematic of the double-slope V/F converter is shown in the figure 1. The Wheatstone bridge converts a strain (x) into a voltage signal, giving by equation (1).

$$\Delta V_{in} = \frac{x}{2R + x} \frac{V_{dd}}{2} \approx \frac{x \cdot V_{dd}}{4R} \quad (1)$$

Here x can vary only in a swing of $\pm 20\Omega$ and $R=5k\Omega$.

The voltage signal is then converted to a triangular signal by the integrator following with a frequency varying proportionally with the input voltage. The triangular signal swing and its slope switching is controlled by the hysteresis comparator, giving by

$$V_{cmax} = \frac{V_{dd}}{2} \left(1 + \frac{R1}{R2} \right) \quad (2) \quad V_{cmin} = \frac{V_{dd}}{2} \left(1 - \frac{R1}{R2} \right) \quad (3)$$

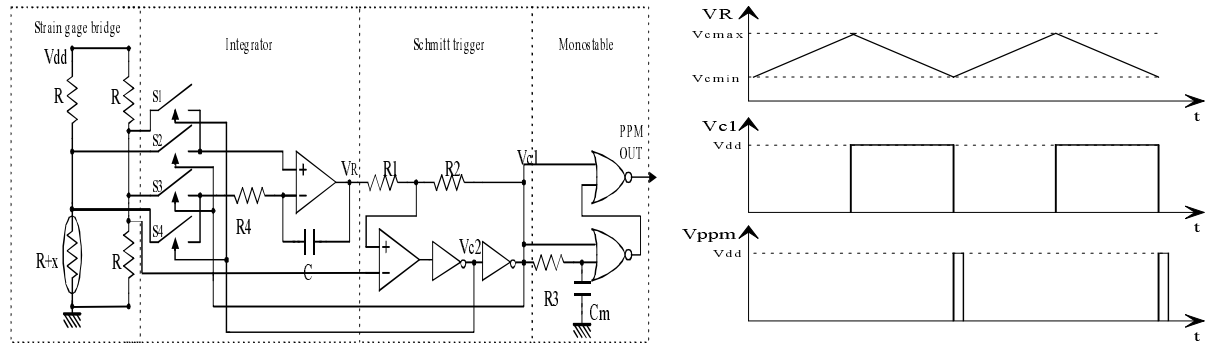


Figure 1 Double-slope V/F converter and its chronographs.

To reduce the power consumption, before radiotransmission, the signal is coded into a PPM (Pulse Position Modulation) signal by a one-shot circuit. Hence the PPM signal has the same frequency as the triangular one, which after simplification can be described by the following equation:

$$f = \frac{x}{2R} \frac{1}{4RiC} \frac{R1}{R2} \quad (5)$$

In reality, neither opamps nor comparators are offset-free. At the presence of comparator's offset (V_{osc}), V_{cmax} and V_{cmin} become

$$V_{cmax} = \frac{V_{dd}}{2} \left(1 + \frac{R1}{R2} \right) + V_{dosc} \quad (6) \quad V_{cmin} = \frac{V_{dd}}{2} \left(1 - \frac{R1}{R2} \right) + V_{dosc} \quad (7)$$

After a double-slope integration, the signal frequency is not changed, because the integration swing is not changed. So the influence of V_{osc} is cancelled automatically.

Unlike the comparator's offset, the opamp's offset (V_{osa}) will change the frequency of the PPM signal to f_{os}

$$f_{os} = \frac{1}{RiC} \frac{R1}{R2} \frac{2R+x}{x} \left[\frac{x^2}{4(2R+x)} - \frac{V_{osca}^2}{V_{dd}^2} \right] = f + \Delta f \quad (8)$$

We can see, from equation (8), that at the presence of V_{osa} , the output depends on not only x but also V_{osamp} and the power supply (V_{dd}). It will be changed by V_{osa} and instability of V_{dd} . So an offset trimming is necessary.

A modified schematic with offset trimming is shown in the figure 2 [2] [3]. One of its equivalent circuit is presented in the figure 3. In this modified schematic, a second opamp is added in such a way that integration can be shared by two integrators alternatively during each period: when one opamp is connected as an integrator, the other is in configuration of offset trimming and offset cancelling charges are stored onto the capacitor C_{sto} . In the next half period, the two opamps exchange their functionality. The offset-free opamp is connected as an integrator. Finally we can have an offset-free integrator during a complete period.

The switching between the two opamps is effected by the second hysteresis comparator added, which has the threshold voltages around $V_{dd}/2$.

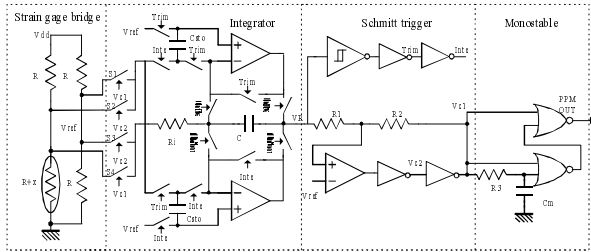


Figure 2 V/F converter with offset trimming

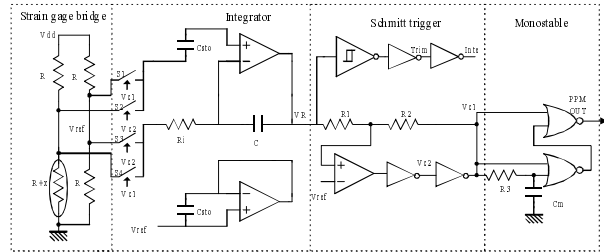


Figure 3 Equivalent circuit of figure 2

Realization

We have realized the V/F converter in a 1.2μ BiCMOS technology for an application to a biotelemetry system. This converter will be installed inside a human body together with a radio transmitter. The signal received by an extracorporeal reception system will permit a survey of the recovery of a bone injury. In this kind of application, it is important to have a minimum power consumption, for the intracorporeal circuit is turned on by an inductive power supply. So we have limited the upper frequency inferior to 1KHz and chosen a 4V power supply. The lower frequency is determined by human walking frequency which is about 100Hz. According to Nyquist theory, a minimum frequency of 200 Hz should be chosen in order to recover completely the information.

To have a working frequency in the required range, a greater time constant for the integrator has to be chosen. i.e. for a range of 200Hz to 600Hz, R_iC is in the order of $10\mu s$, which corresponds to a choice of $R_i=56K\Omega$ and $C=150pF$. There are two problems in realizing such a capacitor: it occupies a great surface ($466 \times 466\mu m^2$); it is more complicated to design an opamp for such a great capacitive load. In our design, we have chosen a capacitor of 20pF instead of 150pF, which requires a surface 7.5 times smaller ($170 \times 170\mu m^2$). The frequency produced is converted into the required range by a two-stages frequency divider, which takes only a surface of $176 \times 120\mu m^2$.

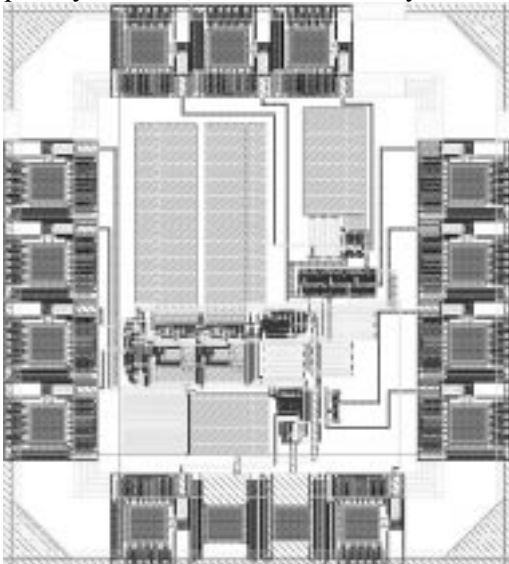


Figure 4 Layout of the V/F converter

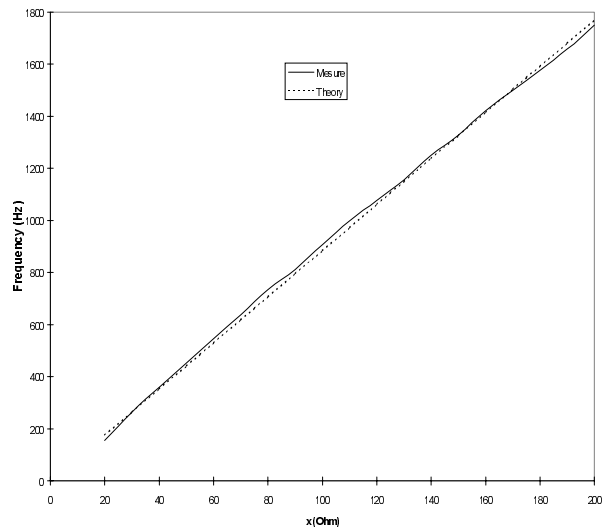


Figure 5 Linearity of f versus x

Results and discussions

The layout of the V/F converter realized is shown in the figure 4, which occupies a total surface of $1690 \times 1455\mu m^2$.

The variation of the output frequency (f) with the change of strain gage (x) is measured and depicted in the figure 5, in which the theoretical result is shown together. A good linearity can be seen and a better coherence between the theory and the test can also be observed. The small difference can be explained by the fabrication accuracy which is about 20% for resistors and 10% for capacitors.

The measured output signal of integrator and comparator are presented in the figure 6. We can see that the integration is well accomplished by two integrators. The measured result shows that the residual offset is less than 0.6mV, which represents an offset reduction of 10 times.

For a variation of x from 100Ω to 200Ω, a variation of current from 1.14mA to 1.18mA is observed, which corresponds to a power consumption less than 4.8mW. Among the total power consumption, there are the two thirds devoted to strain gage which is the model inevitable due to up-to-date fabrication technology. Finally there is only 1.52mW consumption coming from the converter circuitry.

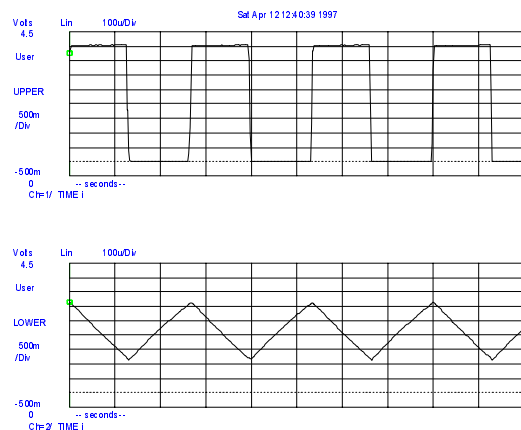


Figure 6 Integrator's and comparator's output signal.

Conclusion

In this paper, a V/F converter with offset trimming is presented. Advantages of the converter are its simplicity in structure, insensibility to instability of V_{dd} in absence of offset, which is very important in inductive power systems and economy in power consumption. The results of test show an offset reduction more than 10 times, a good linearity of frequency variation with input voltage and a very low power consumption.

References

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