Fully Integrated AC Impedance Measurement Technique for Implantable Electrical Stimulation Applications

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Abstract - *Major problems encountered during electrical stimulation are related to the electrodes' contact with tissues. Despite its complexity, that contact can be well characterized by its AC impedance. This technique, also used in numerous biomedical researches, was not easy to integrate in implantable stimulators. Recently, the progress in microelectronics technology allows us to build a fully-integrated circuit to measure the AC impedance of the electrode-tissue contact in implantable stimulator. This circuit, presented in this paper, allows to bypass external laboratory equipment such as signal generator, frequency analyzer, scope, or computer which are generally connected to the implantable stimulators through percutaneous wire. The technique proposed in this paper uses an available stimulator current source and an integrated sine waveform current generator to provide the needed current. Then, the electrode peak voltage is measured as well as the phase shift between that voltage and the sinusoidal current. All those informations are converted into frequency. This technique enables an adequate in vivo characterization of electrodes-tissues contact in order to ensure safety, reliability and efficiency of the stimulation. It has been implemented using a 3.3V, CMOS process. Simulations give satisfactory preliminary results, and the integrated circuit is presently under fabrication.*

Keywords: Impedance measurement, Sine generator, Electrodes-tissues contact, Implantable stimulators, CMOS integrated circuits.

1. Introduction

Impedance measurement is used in a great number of application for characterization purposes [1]. It has been used recently to monitor the electrodes-nerve contact in bladder stimulators [2]. However, used in implantable stimulators, Impedance measurement has often been limited to the measurement of the electrode peak voltage during stimulation. Since the contact between electrodes and tissues determine the quality of stimulation, it should be characterized adequately. The lake of a system intended to measure accurately the electrodes-tissues contact (ETC) is probably due to the dimension of equipment such as a frequency generator, scope or computer. This paper presents an approach to measure accurately the ETC impedance in implantable stimulators without any external component. The measurement technique is described in section 2. This technique is based on a sine current generator presented in section 3, followed by some simulation results in section 4.

2. The measurement technique

To perform an AC measurement, we proposed a system shown in Fig.1. A sinusoidal current is provided by a sine generator which is driven by a 8-bit current source. The current produced by that module is directed towards a pair of electrodes, and the voltage across these electrodes is monitored and processed by the measurement module. Therefore, the proposed system make it possible to evaluate ETC impedance on-chip.

The miniaturization of the measurement system has been made possible by realizing a integrated, low-area, sine current generator, and designing suitable measurements circuits. The sine current required must have a frequency and amplitude harmless for the living tissues surrounding the electrodes. Once this current is applied to a pair of electrodes, two informations are sufficient to calculate the ETC impedance.

The first information is the amplitude of the voltage appearing across the two electrodes. The second is the phase shift of that voltage with respect to the sine current. The amplitude of the electrode voltage is extracted by a peak detector. However, That voltage is first filtered to eliminate eventual glitches. The phase detection is done by a comparator which generates a pulse proportional to the phase shift of the electrodes voltage. Both amplitude and phase shift are converted into a digital format which is less sensitive to noise, and can be easily transmitted to an external controller via an electromagnetic link [3]. The principle of the conversion is simple and does not require too much silicon area. The measured amplitude is first converted into a frequency with a voltage controlled oscillator (VCO).

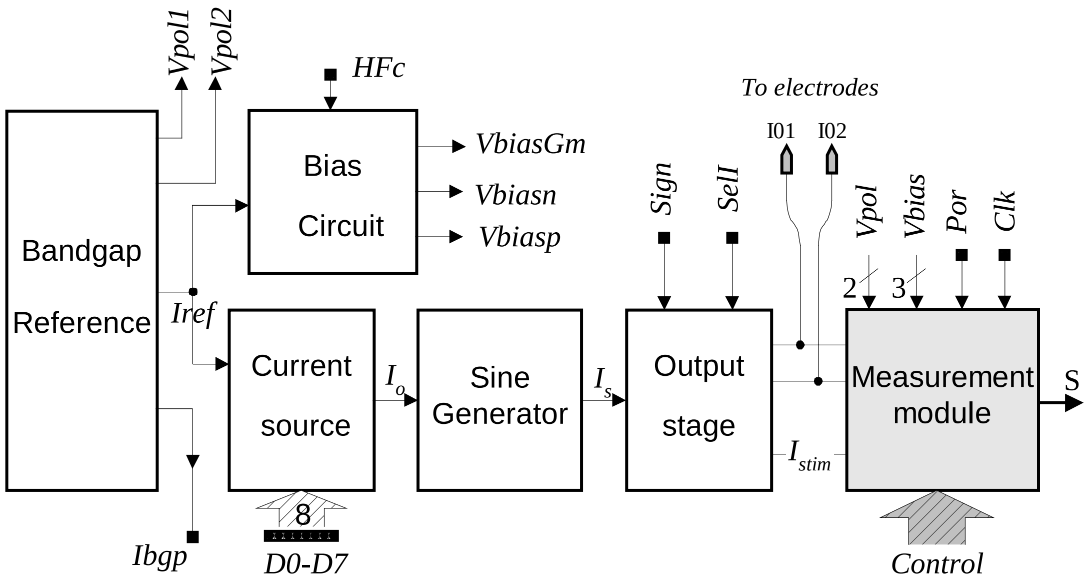

Fig. 1: Block diagram of the complete AC impedance measurement system.

Then, during a fixed time duration, the pulse of the VCO output are counted. To convert the measured phase into a number, the clock pulses are counted during the pulse duration representing that phase. Lets V_p and Δt be measured peak voltage and the phase shift respectively. ETC impedance module |Z| and phase φ can be obtained by the following equations

$$|Z| = \frac{V_p}{I} \tag{1}$$

$$\varphi = \Delta t \frac{2\pi}{T_{\sin}} \tag{2}$$

where I and T_{sin} are respectively the sine current amplitude and period.

3. The sine current generator

There are several techniques to produce a sine waveform. One of them involves an amplifier connected to a filter. That technique is realistic only when implemented with discrete components. Another technique is based on a direct digital synthesizer (DDS) [4]. Although it can be implement on a chip, it required a sine look-up table an digital to analogue converter (ADC), an adder or a finite state machine. It is thus difficult to implement in applications where silicon area and power minimization are essential such implantable stimulators. Also, the accuracy of waveforms is tightly related to the size of the ADC.

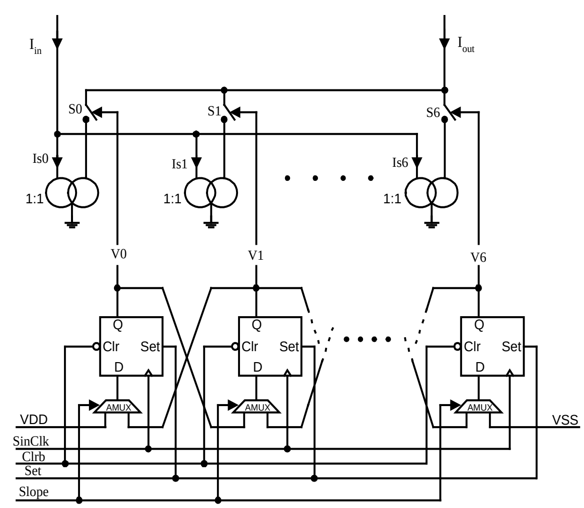

Fig. 2. Schematic of the sine generator.

The approach we propose take into account the architecture of a typical stimulator which already includes a current source. The sine generator just converts a DC current provided by the stimulator current source into a sine current. Its principle relies upon seven controlled current mirrors as shown in Fig.

2. An input current goes through several current mirrors to produce sine steps. After the reset, ‘1’ are propagated through the flip-flops to create an quarter of the sine waveform. ‘0’ are then propagate in the opposite direction to complete an half of the sine waveform. We obtain a rectified sine waveform which is transformed into a completed sine waveform by the output stage. Transistors sizes has been choose according to sine value and matching requirements.The proposed sine current generator presents many important features :

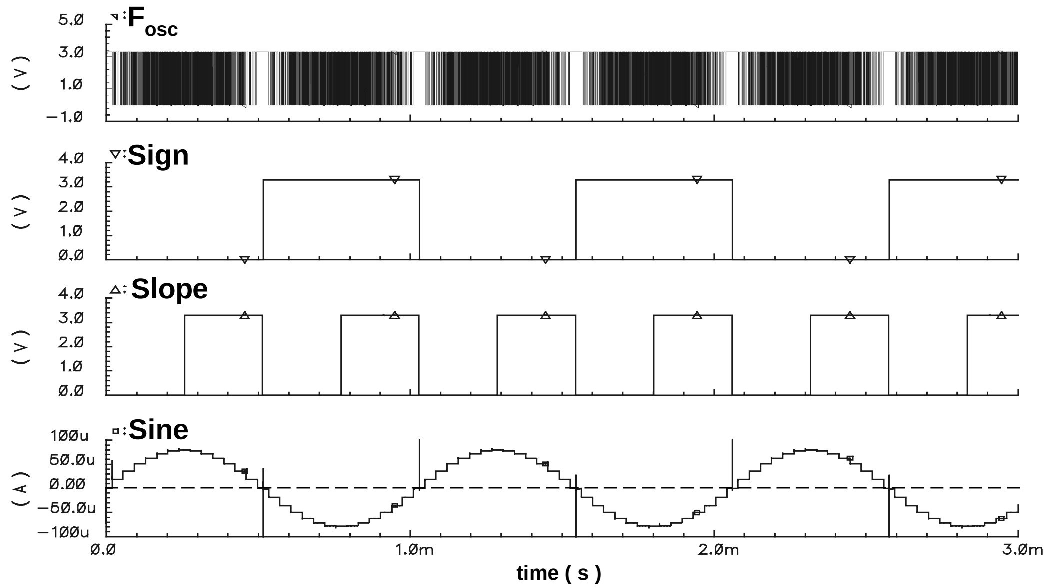

Fig. 3: Simulation results of the sine generator.

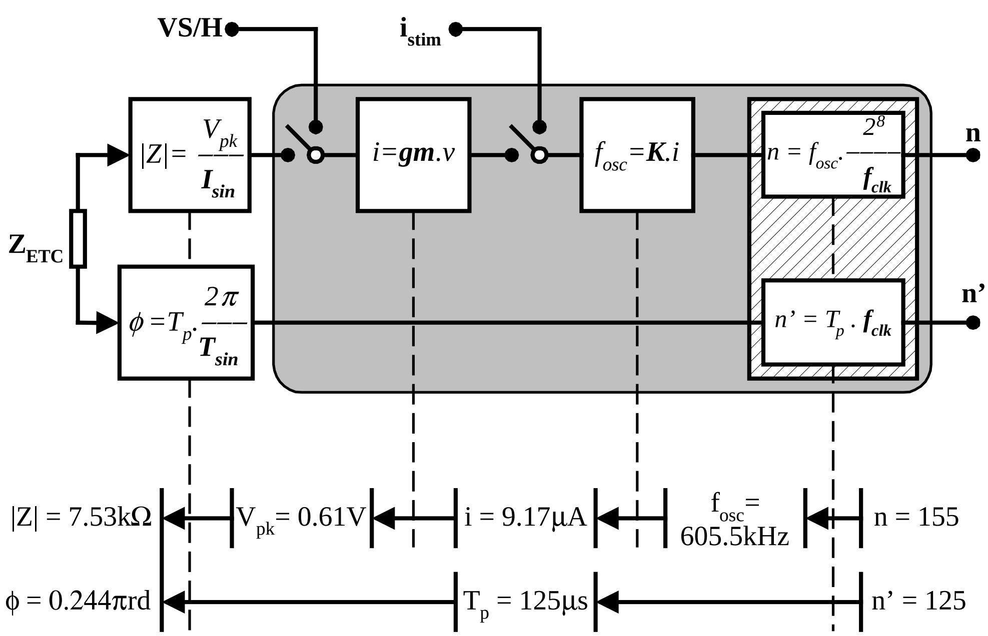

Fig. 4: Synoptic diagram of the measurement process with an example of impedance extraction from measurements (T_{sin} = 1024µs; K = 66kHz/µA; gm = 15µA/V; f_{clk}= 1MHz).

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- it does not need a ROM, so it presents a reduced area;
- it does not need additional bits to produce the sine waveform;
- it offers easy to control sine waveform parameters;
- a more accurate sine waveform is obtained since sine steps are implemented with predetermined transistor's sizes;
- it can also work as a current switch. When every flip-flop is set to '1', the sine generator acts as a simple current mirror, copying the input current to the output;

the flip-flops can be connected serially to ensure testability of the module.

4. Results

Simulation results showing the sine current are presented in figure 3. In this figure Signals Sign and Slope are used to control the half and the quarter of the sine waveform. The signal Fosc is sine current converted into frequency. We can see how accurate is sine waveform especially near the peak current.

The sine current generator with other modules presented in figure 1 have been assembled in a chip. In order verify the accuracy of that device, a simulation based validation has been performed on a arbitrary value impedance of 10 kΩ ($|Z|$=7.07kΩ; $\varphi = \pi/4$). We obtained ($|Z|$=7.53kΩ; $\varphi = 0.244\ \pi$) as shown in Fig. 4.

These results are very satisfactory since the entire process is done on–chip. The chip, which has been implemented on a 0.35 micron CMOS technology, occupy an area of 0.6mm^2 an consume a maximum power of 4.5mW. However it allows an adequate characterization of the ETC in vivo an in vitro.

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