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The Simulation of Current Generator Design for Multi-Frequency Electrical Impedance Tomograph

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Abstract—**In the development of new generation EIT systems, the design of a steady current generator with broad bandwidth is an important consideration. In this paper, the current generator is constructed by enhanced Howland circuit with high-speed operational amplifier. The electronic models of current generator built on Orcad® PSpice 9.2 software are simulated to observe the output current stability at multi-frequencies. As results, the THS4021 model provides stable output current at the frequency ranging from 10 k to 1 MHz with the load for 200-2 kΩ. Furthermore, it also offers higher output impedance that equal to 2.1 MΩ at 1 MHz. The results of simulations provide useful approaches of current generator design for EIT system.**

Keywords—**Electrical Impedance Tomography (EIT), current source, current generator**

I. Introduction

Electrical Impedance Tomography (EIT) is a system that produces the electrical impedance image of the cross section of the body based on the application of current and measurement of voltage from the periphery. The impedance may be represented as two parameters such as resistivity (conductivity) and permittivity. It provides the electrical property of the tissue inside the body.

The hardware design of EIT system includes (1) Digital oscillator circuit, (2) Current generator, (3) Control and data acquisition system, (4) Voltage measurement circuit, and (5) Electrode array. Since the accuracy of the imaging heavily depends on the precision of the applied current, the design of steady current generator is an important consideration [1].

The new generation EIT systems are generally operated on a wide frequency range to produce a series of dynamic images, which is helpful to reveal more information [2] [3] [4]. When the system is operated at higher frequency and wide frequency range, the current generators need to provide stable and accurate output current at the same condition. Therefore, in current generator design, there are some factors should be considered to maintain steady output current.

In Biomedical Imaging and Instrumentation Laboratory (BINIL, NCKU,) the 3rd generation EIT system (EIT-3) was already developed. The EIT-3 system is shown in Fig. 1. The EIT-3 system contains 32 independent current channels and operates at 19.53 kHz. A one-step Newton-Raphson based image reconstruction is used to produce the static imaging. The next generation EIT system (EIT-4) is also in the stage of development, which will extend to the fields of medical applications. In the desired specifications, the EIT-4 will be based on modularized design such as extensible electrode channels with individual current generator. It will be operated at multiple frequencies with higher frequency. For these reasons, the current generator design also needs to be considered. The main specifications of EIT-3 and EIT-4 are listed in Table 1.

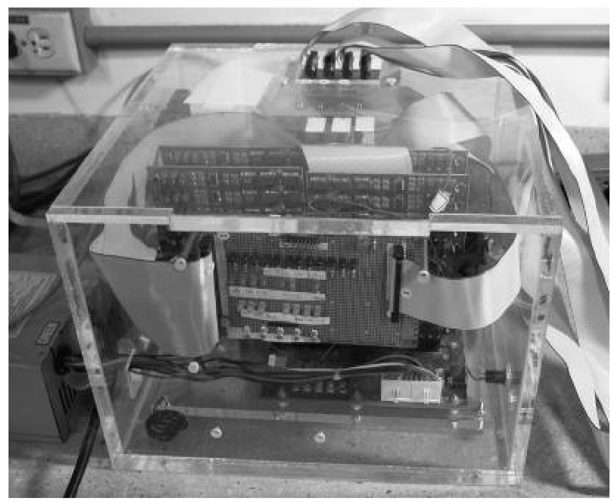

Fig. 1. The EIT-3 system

TABLE 1.
THE MAIN SPECIFICATIONS OF EIT-3 AND EIT-4

	EIT-3	EIT-4
Number of electrodes	32	Extensible
Carrier frequency	Single-Freq. 19.53 kHz	Multi-Freq. 1 k-1 MHz
Current channels	32	Extensible
Current pattern	Sinusoidal	Sinusoidal
Sampling rate	500 kSPS	More than 1 MSPS
Resolution	16 bits	16 bits
Reconstruction method	NOSER	NOSER
Imaging type	Static	Dynamic

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II. METHODOLOGY

The new design of current generator must be suitable for the operation conditions of new generation EIT systems. Therefore, the circuit structure, selection of operational amplifiers, and some tips for practical applications will be discussed below.

A. The Circuit Structure of Current Generator

In EIT system, the current generator designs are usually constructed by these circuit structures such as (1) current mirror type, (2) multi-Op Amps feedback type, and (3) enhanced Howland circuit [5].

The structure of enhanced Howland circuit uses only one operational amplifier and some passive components [6]. Hence, it has widely applied in multiple current channels EIT systems and new generation EIT systems [7] [8].

The schematic diagrams of enhanced Howland circuit are shown in Fig. 2.

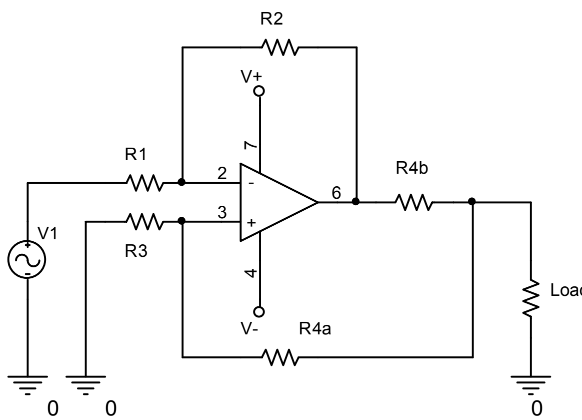


Fig. 2. Enhanced Howland circuit

The mathematic derivation of enhanced Howland circuit can be summarized in the following.

The output current I_L of this circuit is computed by equation (1):

$$I_L = -\frac{V_1}{R_{4b}}\frac{R_2}{R_1} \tag{1}$$

The output current I_L is controlled by signal source V_1 and resistance ratio R_2 / R_1, as well as current sense resistor R_{4b}. Thus, the output current will be independent of load. Its ideal output impedance is given by equation (2):

$$R_{out} = \frac{R_1 R_{4b}(R_3 + R_{4a})}{R_2 R_3 - R_1(R_{4a} + R_{4b})} \tag{2}$$

When the resistance ratio meets the condition as equation (3):

$$R_2 R_3 = R_1(R_{4a} + R_{4b}) \tag{3}$$

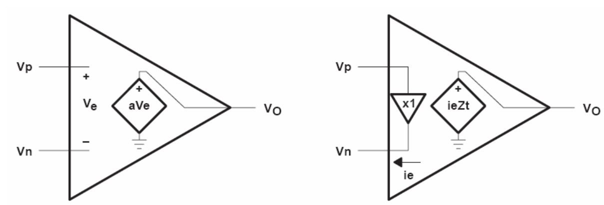
The ideal output impedance will be equal to infinite.

B. Operational Amplifier Models

The operational amplifiers (op amps) of the current generator must be operated at the wide frequency rage higher than 1 MHz. So, the selection of the op amps will be emphasized on the characteristics of high speed.

Gain-Bandwidth (GBW) and Slew-rate (SR) are both general and useful indexes to represent the frequency response and performance of high frequency in op amps. For high frequency applications, op amps will have better performance with higher GBW and faster SR.

The architecture of op amps is another consideration. The op amps have two different feedback architectures such as voltage-feedback type (VFB) and current feedback type (CFB). The both ideal models are shown in Fig. 3. The main differential feature of the architecture is the inverting input impedance. Hence, the stability of CFB op amps operation will depend on the specific value of feedback resistor necessarily [9]. Even though the CFB op amps have more features better than VFB op amps in the high frequency operation such as the faster Slew-rate and independent Gain-Bandwidth, it has the some limitations mentioned above. Therefore, VFB op amps will be better choice for the enhanced Howland circuit.



(a) VFB ideal model (b) CFB ideal model

Fig. 3. The ideal operational amplifier model [9]

In the simulation models, the high-speed op amp THS4021 is used, which is made by TI Instrument. It has the characteristics suitable for high frequency applications, such as 1600 MHz GBW and 470 V/μs SR, as well as VFB op amp architecture.

In order for understanding the effect of the high speed op amps, the other general purpose op amp is selected for comparison. LM833 is a general purpose precision op amp that is made by National Semiconductor. It has 15 MHz GBW and 7 V/μs SR, as well as VFB op amp architecture. The main features about both op amps are presented in Table 2.

TABLE 2.
THE COMPARSION OF BOTH OPERATIONAL AMPLIFIERS

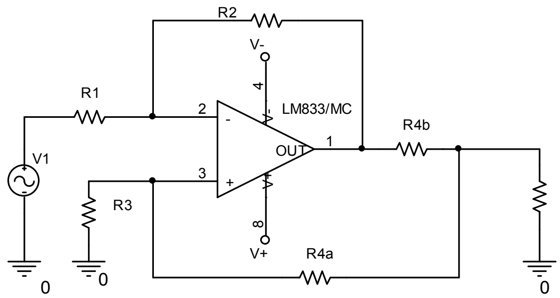
	LM833	THS4021
Gain-Bandwidth	15 MHz	1600 MHz
Slew-rate	7 V/μs	470 V/μs
Support voltage	±18V	±15V
Architecture	VFB	VFB

III. RESULTS

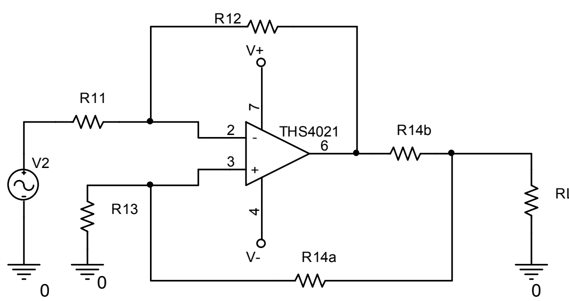
The electronic models of current generator are built on Orcad® PSpice 9.2 software.

In enhanced Howland circuit of both simulation templates and models, the THS4021 spice model which is published by TI Instrument, is used, and the other was LM833 spice model, which is embedded in database of PSpice 9.2 software.

The simulation models of both op amps are shown in Fig. 4.



(a) Enhanced Howland circuit with LM833



(b) Enhanced Howland circuit with THS4021

Fig. 4. The simulation models of both operational amplifiers

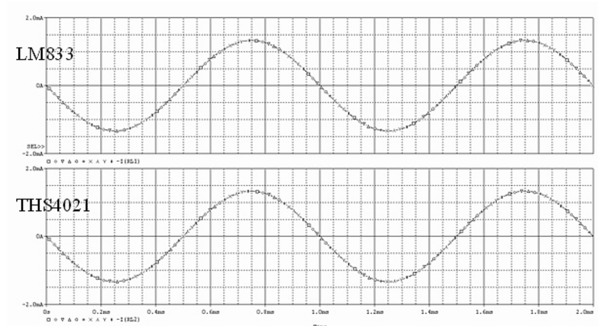
In simulation, the output current stability of both models would be observed under the conditions such as the resistance load from 200 to 2 kΩ and operational frequency from 10 k to 1 MHz.

The simulation results of both models are shown in Fig. 5. At 10 kHz operational frequency, the output current of both models are steady and precise. When the operational frequency increased to 1 MHz, the THS4021 model could produce stable current at this condition. While, the LM833 model shows the poor ability in high frequency operation because the output current is serious distorted.

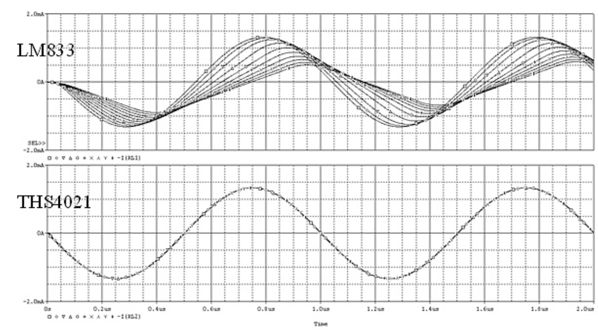
The output impedance is computed by the configurations (Fig. 6) [10]. The resistor R1 value is set to be 100Ω, and the R2 value 1 kΩ. When the switch is in open or closed conditions, the voltage of R1 would be changed by R2. Thus, the output impedance could be computed by the differential voltage for both states. The output impedance could be obtained by equation (4):

$$Z_s = \frac{V_1/V_2}{1-(V_1/V_2)}(R_2 - R_1) \quad (4)$$

The output impedances of both models are computed at 1 k to 1 MHz. At 10 kHz, The output impedance for the THS4021 model is 7.5 MΩ , and for the LM833 model is 13 MΩ. At 1 MHz, the THS4021 model has 2.1 MΩ of output impedance, and the LM833 only has 1.6 kΩ. The detailed results are listed in Table 3.

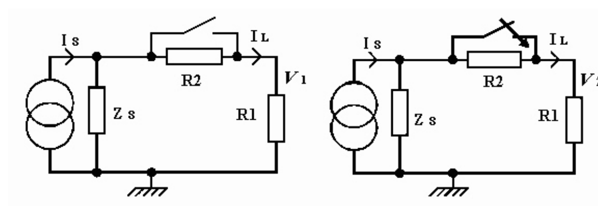


(a) The output current of both models at 10 kHz



(b) The output current of both models at 1 MHz

Fig. 5. The output current stability at different frequencies



(1) Switch opened (2) Switch closed

Fig. 6. The configuration of output impedance computation

TABLE 3.
THE OUTPUT IMPEDANCE OF BOTH MODELS ASSUMING A LOAD VARIATION FROM 100 Ω TO 1 KΩ

	THS4021 model	LM833 model
Frequency (Hz)	Z_{out} (Ω)	Z_{out} (Ω)
1 k	7.5 M	30 M
10 k	7.5 M	13 M
50 k	8.2 M	1.8 M
100 k	10 M	517 k
200 k	10 M	145 k
300 k	13 M	63 k
1 M	2.1 M	1.6 k

IV. Discussion and Conclusion

From the results, the enhanced Howland circuit with the high-speed op amp THS4021 provides better performance at higher frequency. The LM833 model shows the poor performance at the frequencies higher than 100 kHz. But, it performs well at lower frequency range.

Furthermore, the output impedances of both simulation models have decreased obviously, when the frequency is increased. In practical application, the generalized impedance converter (GIC) circuit would alleviate the effect of the output impedance decrease.

The current generator design of EIT system is an important factor for imaging quality. Therefore, recent researches related to EIT hardware design have focused on developing the efficient current generator. We hope that the results of simulations provide useful approaches of current generator design for new generation EIT systems.

Acknowledgment

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