Electronically Tunable Current gain FTFN using OTAs

Somjai Arayawat, Amphawan Chaikla, Vanchai Riewruja, and Thanit Trisuwannawat
Faculty of Engineering, King Mongkut’s Institute of Technology Ladkrabang, Bangkok, Thailand
(Tel: +66-2-739-0758; E-mail: vanchai@cs.eng.kmitl.ac.th)

Abstract: This paper presents the realization of a four-terminal floating nullor (FTFN), which is simple configuration comprised three OTAs. The external bias currents of the OTAs can electronically adjust the current gain of the proposed FTFN. The realization method is suitable for implementation in monolithic integrated form. To demonstrate the circuit performances, the proposed FTFN was simulated by the use of the PSPICE analog simulation program and implemented using the commercially available OTAs. The simulation and experimental results verifying the performances of the proposed circuit are agreed with the theoretical values. Some application example in the design of the proposed FTFN as electronically tunable active element are also included.

Keywords: FTFN, OTAs-based circuit, tunable current gain nullor

1. INTRODUCTION

Tellegen has introduced a concept of ideal amplifier with zero input current and voltage since 1954 [1]. It sets the guidelines for presentation of the nullor by Calin in 1964 [2]. The four-terminal floating nullor (FTFN) consists of two pathological two-terminal elements called a nullator and norator. The nullator found at FTFN input port, whose current and voltage are always constrained to zero. The norator found at FTFN output port, whose current and voltage have undefined values. ‘Floating’ [3] is used here to define that no current is internally leaking always from the port and the current and voltage of the port is not internally dependent on the common-mode voltage of that port.

The concept of FTFN has proven to be the universal active element to synthesize the filters [4], inverse filter [5] and sinusoidal oscillator [6]. Accordingly, there has been much effort to present the implementations of FTFN in integrated circuit technique [7-9]. These approaches have not been implemented with variable current gain. When the current gain of FTFN can be electronically adjusted, the advantage will be gained [10]. This approach is based on the use of operational amplifier (op-amp) and two current mirrors as circuit building blocks. This paper aims to present the similar FTFN with electronically tunable current gain. We develop this idea in the difference way to realize FTFN using three operational transconductance amplifiers (OTAs). This is due to the fact that OTAs are low-cost devices and their transconductance gain can be linearly controlled over more than four decades by means of an external bias current. The allpass filter was implemented using the proposed FTFN as an illustrative application example to demonstrate the advantage of the proposed circuit.

2. CIRCUIT DESCRIPTION

![Fig. 1 Model of tunable current gain FTFN](image1)

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![Fig. 2 The proposed FTFN](image2)

Fig. 2 The proposed FTFN

![Fig. 3 Circuit symbol of the proposed FTFN](image3)

Fig. 3 Circuit symbol of the proposed FTFN

The proposed circuit as shown in Fig. 2 comprises of three OTAs. It is desirable that all OTAs with closely matched characteristics are used. Fig. 3 shows the circuit symbol of the proposed FTFN. Since the OTAs A1-A3 operate as the transconductance amplifier with very high input impedance [11]. Therefore, their input currents are equal to zero written as

\[ I_{i1} = I_{i2} = 0, \quad I_{x} = V_{x}, \quad I_{z} = kI_{w} \]  

(1)

where \( k \) is the current gain of FTFN.

![YX 0](image4)

Fig. 1 Model of tunable current gain FTFN

![VY](image5)

Fig. 2 The proposed FTFN

![VX](image6)

Fig. 3 Circuit symbol of the proposed FTFN

The output current of each OTA as a function of the differential voltage between its inputs can be given by

\[ I_{3} = g_{m3}(V_{Y} - V_{X}) \]  

(5)

\[ I_{w} = g_{m2}(V_{W} - V_{1}) \]  

(6)

The port relations can be characterized by

\[ Y_{X} = 0, \quad V_{Y} = V_{X}, \quad I_{z} = kI_{w} \]  

(2)

\[ I_{1} = I_{2} = 0 \]  

(3)

\[ I_{3} = I_{4} = 0 \]  

(4)
The transconductance gain $g_m$ of the OTA $A_i$ is equal to $I_{B_i}/2V_T$. Where $I_{B_i}$ and $V_T$ are the external bias current of the of OTA $A_i$ and the thermal voltage, respectively. Substituting Eq. (4) into Eq. (5), the input voltages of Y-terminal and X-terminal can be stated as

$$V_Y = V_X$$

(8)

Based on Eqs. (6)~(7), if we design $g_m = k g_m$. The relation between the output current $I_W$ and $I_Z$ can be rewritten as

$$I_Z = k I_W = \frac{I_{B_3}}{I_{B_2}} I_W$$

(9)

where $k = g_m/g_{m1} = I_{B_3}/I_{B_2}$. Eq. (9) shows that the external bias current $I_{B_2}$ and $I_{B_3}$ of the OTA $A_2$ and $A_3$ can electronically adjust the current gain of the proposed TFTFN. Based on Eqs. (2), (8), and (9), it is clearly seen that the proposed circuit in Fig. 2 similarly functions as the tunable current gain FTFN as referred in Eq. (1).

3. RESULTS AND APPLICATION EXAMPLE

3.1 Simulation results and application example

The performances of the proposed circuit were studied by the use of PSPICE analog simulation program. The simulation results was carried out using commercial OTA model as LM13600N. The power supply voltage are set to ±10V. The bias current of the OTAs $I_{B_1}$ and $I_{B_2}$ are set to 0.5mA.

In order to demonstrate the application example of the proposed TFTFN, the tunable current-mode allpass filter as shown in Fig. 7 [12] was simulated. The transfer function of the TFTFN-based allpass filter can be given by

$$\frac{I_{out}(s)}{I_{in}(s)} = \frac{1-(sRC/k)}{1+(sRC/k)}$$

(10)

and

$$\theta_d = -2 \tan^{-1} \left(\frac{sRC}{k}\right)$$

(11)

where $\theta_d$ is the phase angle of the filter.

From the circuit configuration as shown in Fig. 7, If we design $R = 10k\Omega$ and $C = 10nF$, this phase shifter was chosen for a $90^\circ$ phase shift at $\omega_0/2\pi = 1.59kHz$, when $k = 1$ ($I_{B_3} = 0.5mA$). Fig. 8 shows the frequency response of the electronically tunable allpass as shown in Fig. 7 for three different values of the external bias current $I_{B_3}$. Fig. 9 shows the simulation result of the current-mode first order allpass filter with $k = 1$ ($I_{B_3} = 0.5mA$).
The current mode allpass filter using the proposed FTFN is agreed with the theoretical value.

### 4. CONCLUSION

In this paper, a simple configuration for the OTA-based FTFN. The proposed circuit comprises only three OTAs. The current gain can be electronically adjusted by the external bias current of the OTAs. Demonstrated simulation and experimental results are used to confirm the basic circuit performances. The implementation of current-mode allpass filter using the proposed FTFN is the application example.

### REFERENCES


