FOREX Publication
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International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 10, Issue 3 | Pages 411-414 | e-ISSN: 2347-470X

Synthetic Transformer using Operational Transconductance Amplifier (OTA) and Voltage Differencing Current Conveyor (VDCC)

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ABSTRACT- This paper presents a new realization of synthetic transformer using off the shelf active blocks. This proposed transformer is designed using operational transconductance amplifier (OTA), voltage differencing current conveyor (VDCC), resistor and capacitor. Use of VDCC helps to utilizes benefits of both voltage differencing unit and current conveyor. The working of proposed circuit is verified through simulations in LTSPICE using TSMC 180nm process characteristics. The proposed circuit offers the feature of adjusting primary and secondary self-inductances and mutual inductance independently. The bias current of the VDCC is used to control the primary and secondary self-inductance and mutual inductance of synthetic transformer.

Keywords: Synthetic transformer, mutually coupled circuit, OTA, VDCC.

ARTICLE INFORMATION

Author(s): Jyoti Yadav and Bhawna Aggrawal
Received: 04/03/2022; **Accepted**: 15/07/2022; **Published**: 10/08/2022;
e-ISSN: 2347-470X;
Paper Id: IJEER100301;
Citation: 10.37391/IJEER.100301
Webpage-link:
https://ijeer.forexjournal.co.in/archive/volume-10/ijeer-100301.html

This article belongs to the Special Issue on **Recent Advancements in the Electrical & Electronics Engineering**

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1. INTRODUCTION

magnetic coupling between them. Although both coils are physically separated, but there is mutual inductance between the two [2]. Despite the absence of physical connection, the circuit is magnetic coupled and it provides excellent electrical isolation. This coupling can be of either aiding type or opposing type. The advantages that can be achieved using the realization of mutually coupled circuits are as follows [7] (a) Electronically tuneable self and mutual inductance. (b) Uses a grounded capacitor which makes it a preferred choice for integration. (c) Realized using electronic components, avoiding electromagnetic induction.

1.1 Basic Review of Synthetic transformer

A transformer is a mutually coupled circuit that transfers electrical energy between two circuits using electromagnetic induction. It is one of the most fundamental components in the electrical and electronic industries. Its importance and function make it pervasive in almost all domains of engineering. An active synthetic realization of transformer finds application in different electronic domains. A transformer is a 4 port device (two input ports and two output ports) in which self-inductance and mutual inductance are present. An active mutually linked circuit with a mutual inductance (M) primary self-inductance (L_1) and a secondary self-inductance (L_2) is known as the synthetic transformer [5]. *Figure 1* represents mutually coupled circuit [3].

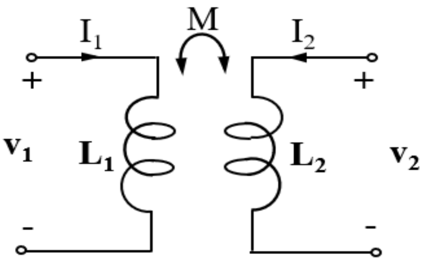

Figure 1: Mutually coupled circuit [3]

1.2 Properties of synthetic transformer

(a) An active realization of a transformer (b) Realization using electronic components without electromagnetic induction (c) Generally requires grounded capacitors (d) Electronically tuneable self and mutual inductance.

There is some correlation between the voltages and currents at the ports of synthetic transformer even in the absence of true magnetic coupling [5]. As a result, they limit the risk of magnetic interference by using only active components, resistors, and capacitors instead of inductive components. They also contain features like electronically tuneable self and mutual inductance, which improve integrability. The main reason for using synthetic transformers is that they provide a wide frequency range. *Figure 2* shows a coupled tuned circuit [7].

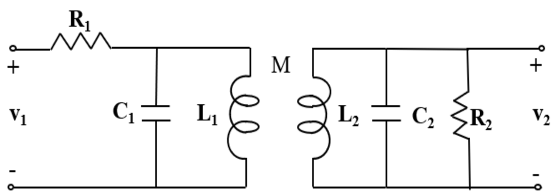

Figure 2: A coupled tuned circuit [2]

The mutually coupled circuit's equation matrix is provided as [2]:

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} sL_1 & -sM \\ -sM & sL_2 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} \quad (1)$$

1.3 Basic Blocks

1.3.1 Operational Transconductance Amplifier

Operational Transconductance Amplifier (OTA) is an active device that acts like a voltage-controlled current source (VCCS). A wide range of applications can be implemented with the help of OTA in the field of analog electronics. The transconductance (g_m) of OTA can be electronically tuned with the help of differential input voltage. Designers generally prefer to use OTA because it facilitates electronic tunability [6]. *Figure 3* shows the block diagram of OTA. Port characteristics are presented in *equation (2).*

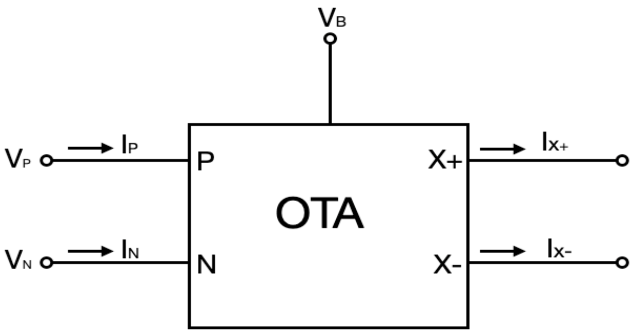

Figure 3: OTA block diagram [6]

$$\begin{bmatrix} I_P \\ I_N \\ I_{X+} \\ I_{X-} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ g_m & -g_m \\ -g_m & g_m \end{bmatrix} \begin{bmatrix} V_P \\ V_N \end{bmatrix} \quad (2)$$

here, in *Figure 3* input currents available at the P and N terminal are given by I_p and I_N respectively. Currents drawn from output terminals X+ and X- are given by I_{X+} and I_{X-} respectively.

1.4 Voltage Differencing Current Conveyor

VDCC comprises of six terminals as shown in *Figure 4*: P and N terminals as input terminals; Z and X are intermediate terminals, whereas W_P and W_N are output terminals [1]. It offers the benefits of the current conveyor along with the voltage differencing unit. Each terminal of VDCC has very high impedance with the exception being X terminal. The symbol of VDCC is shown in *Figure 4. Equation (3) to (7)* shows the port characteristics of VDCC.

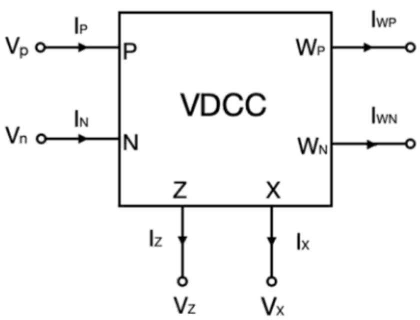

Figure 4: VDCC block diagram [1]

$$I_P = I_N = 0 \quad (3)$$
$$I_Z = G_M(V_P - V_N) \quad (4)$$
$$V_X = V_z \quad (5)$$
$$I_{WP} = I_X, I_{WN} = -I_X \quad (6)$$
$$G_M = \sqrt{\frac{\mu_n C_{OX} W I_{B1}}{L}} \quad (7)$$

2. LITERATURE REVIEW

In [6], an equivalent circuit that is realized using a controlled voltage source is utilized for the simulation of bipolar transistor-based high-frequency mutual inductance circuits. There are several advantages of the circuit arrangement proposed here: The associated voltages created by a bidirectional differential current flowing in one capacitor can be used to imitate two independent inductance elements and their values can be set and modified individually. When this arrangement is applied to various types of mutual induction circuits, a high-frequency circuit with no inductance can be easily obtained. As a result, electronic equipment can be designed with reduced size and weight. A new realization of a mutually coupled circuit was proposed by M. Higashimura and Y. Fukui in 1991 using the bipolar transistor (BJT), second generation current conveyors (CCIIs), or operational transconductance amplifier (OTA) as active elements [7]. All these realizations were done with active implementation of required inductances (L_1, L_2, and M) that can be separately tuned electronically, via the resistors of the circuit. These circuits offer a good choice for integration, reason being the use of ground capacitance present in the circuits. In [9], a mutually coupled circuit was realized using an OTA as active element. The circuit comprises of eight OTAs along with two grounded capacitors. In 1991, Takanori Shigehiro and Masataka Nakamura has given a mutually coupled circuit of high frequency using bipolar transistors [9]. The circuit had advantages like transistors used were of NPN type, two inductances can be independently tuned and are realized utilizing a single capacitor with a bi-directional differential current flowing in it. Furthermore, the circuit configuration was symmetrical in nature. The next significant circuit was presented in the year 2004 [4]. It was an advanced CCII based circuit for the simulation of a mutually coupled circuit. This circuit consists of six resistors, six second-generation current conveyors (CCIIs), and two grounded capacitors. It used lesser number of active and passive elements than the earlier reported structures. In 2008, E. Yuce and S. Minaei proposed a circuit that uses four CCIIs, two capacitors and five resistors [3]. It was ideal for fabrication on IC as it uses only ground capacitors. As compared to all earlier proposed circuits this circuit has an advantage of the smaller chip size and lower power dissipation because of reduction in several active and passive elements. In [5] E. O. Gunes, and A. Toker presented a novel circuit. It was a mutually connected circuit topology based on high-performance transconductors. It used just grounded passive components and four active elements (6 in case differential-output devices were not available). Primary and secondary self-inductance, as well as mutual inductance, can all be regulated individually. The entire circuit, which was made up of integrator and transconductor blocks gave good sensitivity and high-frequency performance. It possessed high stability also. In this paper a new realization of synthetic transformer based on

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OTA, VDCC, resistor and capacitor has been proposed. The paper has 5 *Sections* including the introduction section. *Section 2* consists of literature review. Section 3 includes the methodology of the suggested circuit. The results and discussions are given in *Section 4*. Concluding remarks are presented in *Section 5*.

3. METHODOLOGY AND PROPOSED CIRUIT

Routine analysis of *Figure 1* infers following equation:

$$I_1 = \frac{V_1}{SL_1} - \frac{M}{L_1} I_2 \quad (8)$$

$$I_2 = -\frac{M}{L_2} I_1 + \frac{V_2}{SL_2} \quad (9)$$

L_1 and L_2 of *equation (8) and equation (9)* are the primary and secondary self-inductance, whereas M represents the mutual inductance. $L = CRR_0$ is the most generalized way to model inductances. Capacitance (C) and resistor (R) are meant to be shared by all inductances in the proposed topology, such that $L_1 = CRR_1$, $L_2 = CRR_2$, and $M = CRR_M$. *Equation (8)* and *Equation (9)* can be rewritten as:

$$I_1 = \frac{V_1}{sCR_1R} - \frac{R_M}{R_1} I_2 \quad (10)$$

$$I_2 = -\frac{R_M}{R_2} I_1 + \frac{V_2}{SLR_2R} \quad (11)$$

Figure 5 shows the proposed mutually coupled circuit. It is designed with two OTAs, two VDCCs, two resistors, and two capacitors.

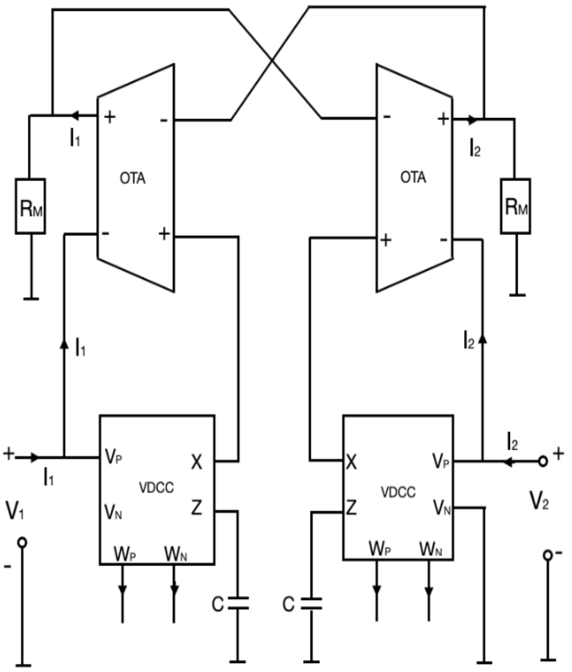

Figure 5: Proposed mutually coupled circuit

The proposed mutually circuit will be used in place of the mutually coupled circuit block as shown in *Figure 6.*

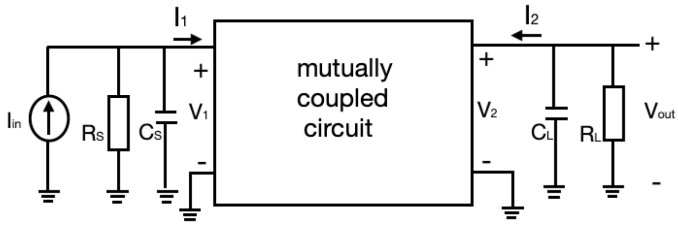

Figure 6: Port termination of a mutually coupled circuit

4. RESULTS AND DISCUSSION

SPICE simulations of the suggested transconductor based MCC (mutually coupled circuit) have been conducted for Vdd=-Vss=1.25V with level 7 model parameters of UMC 0.18µm CMOS process. Simulations for tuned frequency response of the transconductor based MCC shown in *Figure 7* have been observed at $C_S=C_L=25fF$, $R_M=700\Omega$ and $R_S=R_L=450k\Omega$. Variation of transimpedance with frequency for the proposed circuit has been plotted in *Figure 7*. This graph verifies the bandpass behavior of the proposed circuit. For the specified values, the operating range of bandpass filter is observed from 0.3GHz to 0.6GHz.

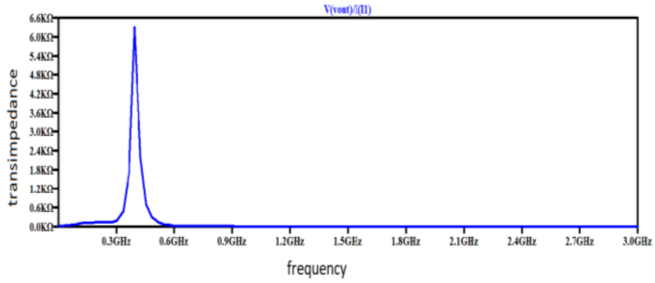

Figure 7: Variation of transimpedance with frequency for the proposed circuit

5. CONCLUSION

A synthetic transformer circuit using 2 OTAs, 2 VDCCs, 2 resistors, and 2 capacitors is proposed in this paper. Simulations of the proposed circuit in SPICE show a bandpass filter type response in output. The proposed circuit has the advantage of electronic tunability and it uses VDCC which helps to get the benefits of both voltage differencing unit and current conveyor. The bias current of the VDCC is used to control the primary and secondary self-inductance and mutual inductances of synthetic transformer.

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