A Low-Voltage Temperature-Compensated Exponential Amplifier using only NPN Transistors

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ABSTRACT

This paper presents a simple circuit design technique for realizing a low-voltage temperature compensated current-mode exponential amplifier using only NPN transistors. The circuit is composed of a current source dependent of temperature, a translinear-based multiplier/divider circuit, and a current mode exponential amplifier circuit. The circuit can operate for a low-level power supply voltage at 2V. The simulation results obtained from the PSPICE program are employed to verify the theoretical prediction. The exponential amplifier demonstrates good characteristic performance and temperature stability.

Keywords: Exponential Amplifier, Current Mode, Temperature Compensated, Translinear, Logarithmic Amplifier.

1. INTRODUCTION

An exponential amplifier is usually employed in the electronic systems, which need to handle wide dynamic ranges of signals, such as, a wide-band array radar, a sonar application, an one of the important building blocks in a variable gain amplifier (VGA)[1-2] and instrumentation applications. The basic principle for realizing the exponential amplifier is usually built by using semiconductor diodes or transistors with operational amplifier. The classical problem with this transdiode configuration is that the performance of the amplifier depends on temperature [3]. Therefore, there has been a strong interest to develop a temperature compensation scheme. Recently, there is strong interest is current-mode exponential circuit, where the applications can be found in the literature [4]. However, one of the disadvantages of this amplifier is the temperature, which is strongly dependent. The purpose of this paper is to propose a low-voltage current-mode temperature compensated exponential amplifier. The proposed circuit employs only NPN transistors, and is suitable for integrated circuit. The PSPICE simulation shows a quite good operation of the circuit.

2. CIRCUIT DESCRIPTION

2.1 Low-voltage Bipolar Translinear-based Temperature Dependent Exponential Amplifier

In the figure 1 shows the basic circuit obtained by inserting only one resistor $R_1$ into the translinear circuit [5], where $I_{1A}$, $I_{2A}$ and $I_{3A}$ are the external bias currents of the transistor $Q_{1A}$, $Q_{2A}$ and $Q_{3A}$, respectively. We have the following relation

$$V_{BE1A} + I_{2A} R_1 + V_{BE2A} = V_{BE3A} + V_{BE4A} \quad (1)$$

The output current $I_{OA}$ is the current flow into $Q_{4A}$, where $V_{BE}$ is the base-emitter voltage , we get

$$V_T \ln \frac{I_{3A}}{I_s} + I_{3A} R_1 + V_T \ln \frac{I_{1A}}{I_s} = V_T \ln \frac{I_{3A}}{I_s} + V_T \ln \frac{I_{1A}}{I_s} \quad (2)$$

where $I_S$ and $V_T$ are the saturation current and the thermal voltage of the transistor, respectively. Assuming that the size of all transistors is same. Thus, equation (2) becomes ,

$$I_{2A} R_1 = V_T \ln \frac{I_{3A} I_{OA}}{I_{1A} I_{2A}} \quad (3)$$

The circuit that realizes from the above function, is shown in Figure 1. Letting $I_{3A}=I_{2A}$, the emitter DC current of the transistors $Q_{2A}$ and $Q_{3A}$ becomes same. Thus we can
directly connect the base of $Q_A$ to the emitter of $Q_{2A}$ and we can delete of $Q_{3A}$ and $I_{3A}$. The equation (3) becomes,

$$I_{2A}R_1 = V_T \ln \frac{I_{OA}}{I_{1A}}$$

(4)

Thus, the output current $I_{OA}$ is given by.

$$I_{OA} = I_{1A}e^{\frac{I_{2A}R_1}{V_T}}$$

(5)

From the Figure 2, we find that another one of disadvantages of the exponential amplifier is strong temperature, which is dependent on the output current $I_{OA}$. The next section, we will introduce the temperature compensated exponential amplifier.

2.2 Low-voltage Bipolar Translinear-based Temperature Compensated Exponential Amplifier

![Fig.3: A Current Source Dependent of Temperature](image)

Figure 3. Show a circuit of a low-voltage current source dependent of temperature, which is show form circuit in the logarithmic amplifier proposed in reference [6]. Assuming that the dimensions of all transistors are same and selecting two resistors are R. Thus, we can realize a current source dependent of temperature as follows,

$$I_9 = \frac{V_T}{R} \ln \frac{I_5}{I_7}$$

(6)

where we have selected $I_5/I_7=e$, then can be written as

$$I_9 = \frac{V_T}{R}$$

(7)

In the figure 4 is a practical realization of the current source dependent of temperature where the output transistor of $Q_9$ is directly connected to input of the next stage for translinear circuit cell of $Q_{10}$ to $Q_{13}$. We will use as temperature-compensated circuit next time, at the transistor $Q_{10}$ to $Q_{13}$, we obtain

$$I_{13} = I_{10}I_{11} \frac{I_{10}I_{11}}{I_{12}}$$

(8)

The transistor $Q_9$, which is the output transistor of the first stage of current source dependent of temperature, behaves as the input transistor of the second stage $Q_{10}$ to $Q_{13}$. Substituting equation(7) into equation(8) , where $I_9=I_{11}$, we obtain the output current of

$$I_{13} = I_{10} \left( \frac{V_T}{R} \right)$$

(9)

The schematic diagram of the proposed circuit for a low-voltage bipolar translinear-based temperature compensated exponential amplifier is shown in Figure 5. The circuit consists of a basic circuit in Figure 2, which is
directly connected to the current source dependent of temperature in Figure 4. Substituting current $I_{10}$ from equation (9) into the current $I_{3A}$ from equation (5), where $R_1 = R$.

$$I_{OA} = I_{1A}e^{I_{12}}$$ (10)

![Fig.5: Temperature Compensated Exponential Amplifier Circuit using Only NPN Transistors](image)

Now, the output current $I_{OA}$ from equation (10) that the circuit should also be relative of the temperature compensated in circuit of Figure 5 Since the circuit can be operated on current mode that has a capability of low power supply voltage of $2V_{BE} + V_{CEsat} + RI = 1.8V$ Where $I$ is the current of $R$. Thus a 2V power supply will be enough and the circuit attractive feature, as the circuit can be employed to implement only NPN transistor action.

### 3. SIMULATION RESULTS

To verify the theoretical design, the proposed low-voltage bipolar translinear–based temperature compensated exponential amplifier was simulated to confirm the characteristic of the circuits using the PSPICE program. We use the NPN transistors 2N3904 model obtained from the PSPICE library. The simulation results are shown in figure 6 for various values the power supply used is +2V and $R=260\Omega$. The bias currents $I_5$ and $I_7$ are chosen to be $272\mu A$ and $100\mu A$, respectively, to give a value of ratio $I_7/I_5 = e$. The bias currents $I_{10}$ and $I_{12}$ are set to $100\mu A$ and the current $I_{10}$ is input current signal.

Figure 6 shows the simulated and calculated DC transfer characteristic of the proposed exponential amplifier for the input signal current $I_{10}$, which is varied from 0 to $300\mu A$.

It can be seen that the resulting characteristic is precisely relate to the exponential function is good agreement with theoretical analysis with the error less than 0.5%. The simulation results shown in figure 7 exhibit the values of the output current against temperature for the case of uncompensated and compensated exponential amplifier of figure 2 and figure 5 for $I_{3A}$ and $I_{10}$ are equal to $100\mu A$, respectively. By varying the temperature $-40^\circ C$ to $100^\circ C$, it is readily seen that the temperature performance of the compensation circuit is much better than the uncompensated circuit. The sensitivity of circuit with temperature of the uncompensated and compensated circuits are approximately equal to 0.99 and 0.03, respectively.

![Fig.6: DC Transfer Characteristic of Exponential Amplifier for figure 5](image)

![Fig.7: Variation of the Output Currents $I_{OA}$ against Temperature of Fig.2 and Fig.5](image)

![Fig.8: Frequency Characteristic of Exponential Amplifier for figure 5](image)
The figure 8 and 9 show the frequency and phase response of the output current $I_{OA}$ of the current-mode temperature compensated exponential amplifier of figure 5, respectively.

It is clearly shown that the circuit can be used up to frequency around 160 MHz at phase shift approximately to 90 degree

![Graph showing phase response]

**Fig.9 : Phase Response of Exponential Amplifier for figure5**

4. CONCLUSION

We have proposed a low-voltage temperature compensated exponential amplifier using only NPN transistors that can operate in the current mode and at a power supply voltage as low as 2.0 volts or less. The special features of the proposed circuit are the insensitive of temperature and the suitable structure for IC fabrication, the circuit attractive feature, as the circuit can be employed to implement only NPN transistor action. Demonstrated simulation resulted confirmed the circuit performance.

5. ACKNOWLEDGEMENT

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6. REFERENCES


