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DAMPING COEFFICIENT DETECTOR FOR DAMPED OSCILLATION

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Abstract. *In this research, the damp coefficient detector of damped oscillation is designed by analog signal processing and also relies on the current conveyor, which is indicated. It consists of four parts: a peak detector, a logarithmic amplifier, a limiting circuit and a differentiator amplifier. The peak detector output voltage has achieved the DC voltage which decays exponentially with time. Then, it is converted by the logarithmic amplifier in order of the linearity decays of the voltage and is revealed as the negative slope. Since the magnitude voltage of the peak detector is decreased until it rapidly approaches to zero, the analysis will not be in accordance with the idealized case. Thus, the limiting circuit is connected in front of the differentiator amplifier. This circuit functions as a maximum detector between the logarithmic amplifier and one of constants. Finally, the differentiator amplifier is applied to determining the derivative of limiting circuit output voltage. While, the input voltage indicates the under damped oscillator which is acquired by the RLC circuit and is investigated by distinct conditions. Consequently, the output signal obtains a DC voltage signal which has direct proportion with a damped oscillation. In addition, the relation between the analysis and PSPICE simulation results is also consistent.*
Keywords: Damped oscillator, Damping coefficient, Detector, Resonance oscillation, Vibration measurement

1. **Introduction.** The oscillatory motions are the most used principles in order to study in engineer and physics field [1]. It is a fundamental knowledge of object vibration such as mass, devices and an electrical signal [2-6]. All of the systems are considered for ideal system, that is, the system that oscillates indefinitely under the action of only one force or a linear restoring force. Many actual systems present that the non-conservative forces such as friction can retard motion. The mechanical energy of the system diminishes that compared with time and the motion is called to be damped. Therefore, an influence of other damped oscillations [7] is caused that a displacement decays exponentially with time and a damp constant. However, the damp constant of all oscillations that was measured will not only be used for the experimentation but will be also applied to the structural assessment and the qualification of other mechanics [8]. The general practice measures a damp constant of an oscillation such as a displacement of an object or a magnitude of signal that is applied to calculating by computer in order to determine a variety of it. The

aforementioned implement to an oscillation is employed that it will not only cause a large size, high cost but will also depend on a procession of a computer. The aforementioned research to the oscillation is considered which each research is designed as various systems. Thus, this research proposes a design to the measurement oscillation. Accordingly, this research is mainly oriented on damping coefficient detector for damped oscillation which was designed and analyzed of the system. In addition, this damped coefficient detector was designed by an analog signal processing and also relies on the current conveyor. And, it consists of four parts, which are a peak detector, a logarithmic amplifier, a limiting circuit and a differentiator amplifier. The peak detector output voltage achieves the DC voltage which decays exponentially with time. Then, it is converted by the logarithmic amplifier in order of the linearity decays of voltage and is revealed as the negative slope. While, the magnitude of the peak detector is decreased until it rapidly approaches zero, and the analysis will not be in accordance with the idealized case. Thus, the limiting circuit is connected in front of the differentiator amplifier. This circuit functions as a maximum detector between the logarithmic amplifier and a constant. Finally, the differentiator amplifier is applied to determining the derivative of the limiting circuit output. Since, the input voltage indicates the under damped oscillator which is acquired by the RLC circuit and is investigated by distinct conditions. This damped coefficient detector is investigated by analysis and PSICE simulation program. As a result of damped coefficient detector oscillation, it causes a DC voltage signal which is directly proportional with the damped oscillation. Consequently, the relation between the analytical and PSPICE simulation results is also consistent. The proposed damping detector for damped oscillation is ideal for the applications such as a suspension system, a micro-electro-mechanical system, a spring-mass system and the laboratory instruments of physics.

2. **Basic Principle.**

The block diagram of the proposed detector is illustrated in Figure 1. It consists of a peak detector, a logarithmic amplifier, a limiting circuit and a differentiator amplifier. The V_{in} voltage indicates the damped oscillator as under damped. The relation solution of the V_{in} and the time can be written as Equation (1).

$$V_{in} = A_o e^{-\gamma t} \sin(\omega t + \phi) \tag{1}$$

where A_o, ω, ϕ and γ represent the magnitude, the angular frequency, the initial phase and the damp coefficient of the oscillation, respectively.

From Equation (1), it is important to note that the solution consists of two distinct parts. The first term contains the magnitude and the exponential factor that is $e^{-\gamma t}$. The remaining terms in Equation (1) involve only since function represents an oscillation that continues indefinitely.

To measure the magnitude of the V_{in} voltage, the peak detector is employed in order to provide the DC voltage which is defined as V_p. The solution to Equation (1) is

$$V_p = k_1 A_o e^{-\gamma t} \tag{2}$$

where k_1 is the scale factor of the peak detector.

Additionally, the V_p voltage decays exponentially with time. Then, it is converted to the linearity decay of voltage by the logarithmic amplifier. Thus, it implies as follows:

$$V_n = k_2 \ln\left(k_1 A_o e^{-\gamma t}/k_3\right) = k_2 \ln(k_1 A_o/k_3) - k_2 \gamma t \tag{3}$$

where k_2 and k_3 are the constants of the circuit.

As seen from Equation (3), the V_n voltage is proportional to the damp coefficient and it revealed as the negative slope. Furthermore, the V_p magnitude voltage decreases until approach zero. As a result, Equation (3) will not be in accordance with the ideal. In order to facilitate of the proposed detector, the limiting circuit is connected in front of the differentiator amplifier. This circuit functions as maximum detector between the V_n

voltage and the DC voltage which is defined as V_b. Thus, the limiting circuit output provides the V_m voltage as follows:

$$V_m = \begin{cases} k_2 \ln(k_1 A_o/k_3) - k_2\gamma t; & V_n > V_b \\ V_b; & V_n \leq V_b \end{cases} \tag{4}$$

Finally, the differentiator amplifier can be used to determine the derivative of V_m voltage as Equation (4). Besides, the differentiator amplifier output which is defined as V_{out} when the V_n voltage is greater than the V_b voltage is implied.

$$V_{out} = k_4 k_2 \gamma \tag{5}$$

where k_4 is the scale factor of the differentiator amplifier. As shown in Equation (5), the V_{out} voltage is linearly proportional to the damp coefficient.

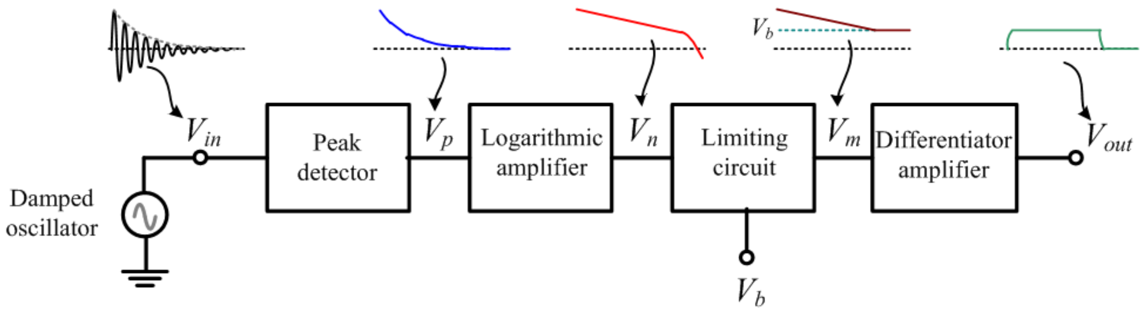

FIGURE 1. Block diagram of the damp coefficient detector

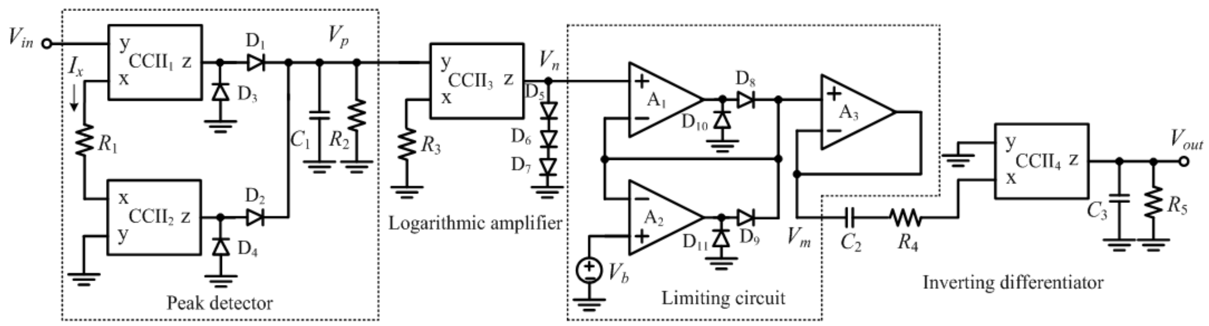

FIGURE 2. The circuit diagram of the proposed detector

3. **Designed Circuit.** Figure 2 illustrates the circuit of Figure 1. The peak detector includes the current conveyors $CCII_1$-$CCII_2$, the diodes D_1-D_4, the resistors R_1-R_2 and the capacitor C_1. Moreover, the V_{in} voltage is converted into the current I_x at the resistor R_1. The diodes D_1 and D_2 conducted the alternating rhythm of V_{in} signal which is plus-minus side. Besides, the diodes D_3 and D_4 limit the reverse bias voltages of the diodes D_1 and D_2. In addition, the capacitor C_1 is connected to the resistor R_2 where they function as a low pass filter and transfer the current signal. Furthermore, it forms as the V_p voltage signal as well. Consequently, the V_p voltage can be approximated as follows:

$$V_p = (2R_2/\pi R_1) A_o e^{-\gamma t} = k_1 A_o e^{-\gamma t} \tag{6}$$

where

$$k_1 = 2R_2/\pi R_1 \tag{7}$$

The current conveyor $CCII_3$ is connected to the resistor R_3 and the diodes D_5-D_7 which function as the logarithmic amplifier. This sub-circuit produces the V_n voltage which relates to the V_p voltage. That is,

$$V_n = 3V_T \ln(k_1 A_o / R_3 I_o) - 3V_T \gamma t = k_2 \ln(k_1 A_o / k_3) - k_2 \gamma t \tag{8}$$

$$k_3 = R_3 I_o \tag{9}$$

$$k_2 = 3V_T = 3kT/q \tag{10}$$

where I_o is the reverse saturation current of the diodes D_5-D_7, V_T is the thermal voltage, T is the absolute temperature (K), k is the Boltzmann's constant ($\cong 1.3806 \times 10^{-23}$ J/K) and q is the magnitude of the electrical charge on the electron ($\cong 1.602 \times 10^{-19}$ C).

The operational amplifiers A_1-A_3 and the diodes D_8-D_{11} are formed, and it conducts the limiting circuit or maximum detector in comparing the V_n and V_b voltages. In addition, it generates the V_m voltage as well. Therefore, the operation of the sub-circuit can be explained as follows: when the V_n is greater than V_b voltage, the diode D_8 was switched-on until the V_m equals V_n voltage and the other would be switched-off. On the other hand, if the V_n is less than V_b voltage, the diode D_9 was switched-on until the V_m equals V_b voltage and the other would be switched-off.

Similarly, the diodes D_{10} and D_{11} are limited to the reverse bias voltages of the diodes D_8 and D_9. Thus, the aforementioned circuit is limited to the magnitude of the V_m at V_b voltage.

The last sub-circuit includes the current conveyors $CCII_4$, the resistors R_4-R_5, and the capacitors C_2-C_3. To respect the frequency domain, the V_{out} voltage is related to the V_m voltage. It yields as Equation (11).

$$\frac{V_{out}}{V_{in}} = -\frac{R_5}{(sC_3R_5 + 1)} \frac{sC_2}{(sC_2R_4 + 1)} \tag{11}$$

where $s = j\omega$. In the case of $\omega < 1/2\pi C_2 R_4$ and $\omega < 1/2\pi C_3 R_5$, the circuit performs as the differentiator amplifier. Consequently, the low frequency components of the V_{out} voltage of time domain can be rewritten as follows:

$$V_{out} = -R_5 C_2 d(V_m)/dt = k_4 k_2 \gamma \tag{12}$$

where $k_4 = R_5 C_2$ is the scale factor of the circuit.

4. **Simulation Results and Discussions.** The implements of the proposed circuit as illustrated in Figure 2 were studied by the PSPICE simulation program. The supply voltages were prescribed to ±9 V. The schematics of the current conveyor, the op-amp and the diode were AD844/AD, UA741 and D1N4148, respectively. Furthermore, the parameters of circuit as $R_1 = R_2 = R_3 = 10$ kΩ, $R_4 = 1$ kΩ, $R_5 = 2$ kΩ, $C_1 = 10$ μF, $C_2 = 50$ μF, $C_3 = 100$ μF, and $V_b = 1$ V were chosen. To investigate the circuit operation, a damped oscillation was constructed by the RLC circuit which was acquired by different conditions as illustrated in Figure 3. This circuit provided the damped oscillation at $\gamma = R/2L$ of the damp coefficient and $f = [(1/LC) - (R/2L)^2]^{1/2}/2\pi$ of the resonance frequency. Additionally, Figure 4 illustrated the various signals of the proposed circuit

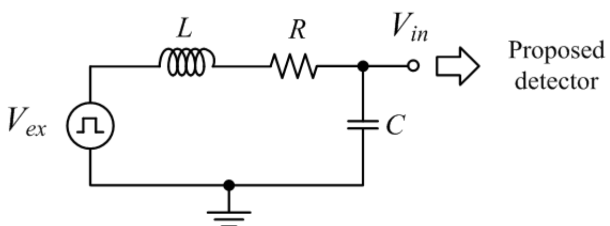

FIGURE 3. The damped oscillation based on RLC circuit

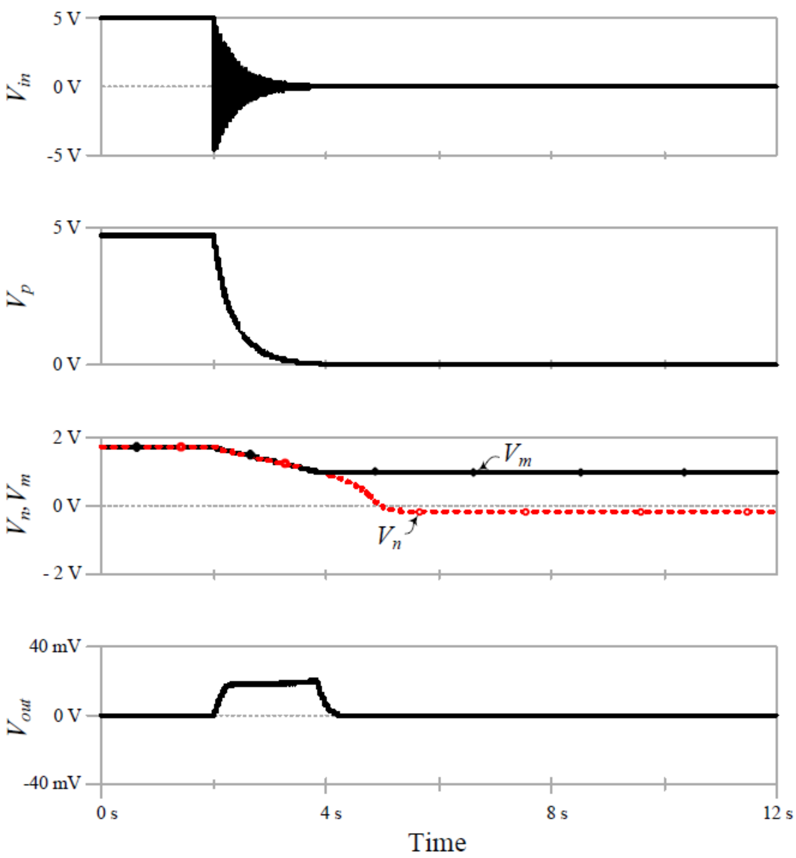

FIGURE 4. The simulation results at $\gamma = 2.5\ \text{s}^{-1}$

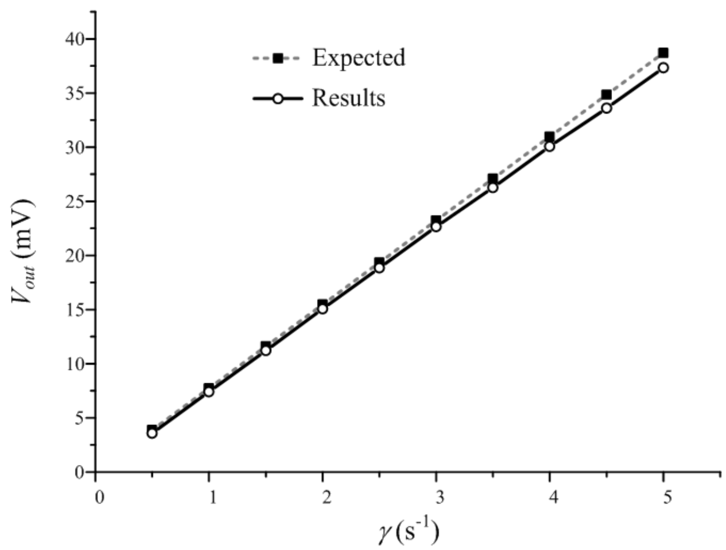

FIGURE 5. The DC transfer characteristics as γ of varying at 0.5-5 s^{-1} of range

where 5 Hz frequency and 2.5 s^{-1} damp coefficient of the damped oscillation were applied. The results were apparent and in accordance with the expected signals as illustrated in Figure 1. Moreover, the results of various damp coefficients are illustrated in Figure 5. It is evident that the relation between the V_{out} voltage and the damp coefficient are linearly at the $R^2 = 0.9991$. In addition, the full-scale error of variation of the damp coefficients is 3.5% which is illustrated in Figure 6.

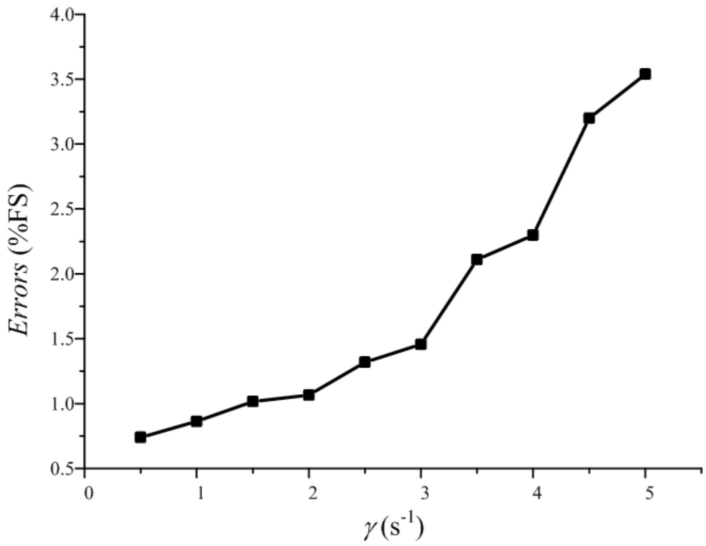

Figure 6. The full-scale error of the DC transfer characteristics

Figure 4 illustrates the simulation results at $\gamma = 2.5$ s^{-1} where the first is the damped oscillation input, the second is the peak detector output, the third is the logarithmic circuit and the limiting circuit outputs and the fourth is the differentiator amplifier output.

5. **Conclusions.** This research aims to propose the damp coefficient detector of damped oscillator. The output voltage has direct proportion with the damp coefficient which has been verified by PSPICE simulation results. The DC transfer characteristic of the proposed detector appears as a good linearity with high R^2 parameter for over entire dynamic range. The experimental results for the damp coefficient detector of oscillator as demonstrated are in accordance with the proposed principle. In order of mechanics oscillation application, the displacement sensors can be applied to the detector of input as well. Moreover, the proposed damping detector for damped oscillation is ideal for the application that is the suspension system, the micro-electro-mechanical system and the laboratory instruments of physics.

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