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Obtaining real-time Bode (analysis) of electronic circuits with LabVIEW

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ABSTRACT

Bode diagram is a term used in many fields of science and engineering that can be described as frequency response analysis. LabVIEW is a multifunctional program for acquiring, processing and analyzing data. In this paper, real time Bode diagram of electronic circuits are obtained in LabVIEW platform without using special VIs(virtual instruments) such as SI Bode Plot VI. In addition to this, the realized study can be easily integrated in to other commonly used platforms such as MATLAB and C to obtain bode diagram results in real time. To evaluate performance of the realized study, Bode diagram results obtained from LabVIEW is compared with the results obtained from ORCAD-PSpice simulations.

Keywords: Bode diagram, real-time applications, LabVIEW, ORCAD-PSpice

Elektronik devrelerin gerçek zamanlı bode diyagramlarının LabVIEW ile elde edilmesi

ÖZ

Bode diyagramı, bilim ve mühendisliğin birçok alanında kullanılan, kısaca frekans cevabı analizi olarak tanımlanan bir kavramdır. LabVIEW; verilerin toplanması, işlenmesi ve analizlerinin yapılabilmesi için çok uygun ve işlevli bir programdır. Bu çalışmada, SI Bode Plot VI gibi özel VI'lar (sanal enstrümanlar) kullanılmadan, elektronik devrelerin gerçek zamanlı bode diyagramlarının LabVIEW programı ile elde edilmesine yönelik farklı bir çalışma gerçekleştirilmiştir. Ayrıca, gerçekleştirilen çalışma, çok sık kullanılan MATLAB veya C gibi diğer platformlara da kolaylıkla entegre edilerek, gerçek zamanlı bode diyagram sonuçları alınabilir. LabVIEW'de elde edilen bode diyagram sonuçları, ORCAD-PSpice benzetim sonuçları ile karşılaştırılarak, yapılan çalışmanın başarımı gösterilmiştir.

Anahtar Kelimeler: Bode diyagramı, gerçek zamanlı uygulamalar, LabVIEW, ORCAD-PSpice

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1. INTRODUCTION

LabVIEW [1] (Laboratory Virtual Instrument Engineering Workbench) is developed as a graphical programming language in 1986 by National Instruments [2]. In the LabVIEW functions are represented with blocks called VIs(virtual instrumentation) and these blocks are connected through input and a-output terminals of VI's. Applications in Labview are automatically run with multiple threads by recognizing code block which can be run in parallel. [3].

LabVIEW is very user friendly since it is a graphical programming language and there is no need for manual memory allocation as in C. Another advantages can be listed as: some of the included libraries hide File I/O implementation and network connectivity and programing is realized by dragging and dropping code blocks. [3]. An additional important feature of LabVIEW is the availability of a comprehensive set of easy-to-use functions dedicated to signal acquisition, processing, and analysis [4].

Bode diagrams were presented to the literature by Bode and Nyquist in 1930's. Bode diagrams are used in many fields of science and engineering as a frequency response analysis of linear and non-linear systems [5-8]. Bode diagrams are consist of magnitude diagram and phase diagram. The magnitude diagram describes magnitude of frequency response of a system while phase diagram describes phase shift in the system's response [9, 10]

Bode plots are usually semilog plots, the magnitude is given in decibels and phase is given in degrees for a desired frequency ranges.

The transfer function of a system can be written as:

$$H(j\omega) = H e^{j\varphi} \quad (1)$$

Here H is the magnitude of the transfer function, φ is the phase of the transfer function.

By taking the natural logarithm of both sides of Equation 1,

$$\ln H(j\omega) = \ln H + \ln e^{j\varphi} = \ln H + j\varphi \quad (2)$$

Equation 2 is obtained. As it is seen clearly in Equation 2, the real part of $\ln H(j\omega)$ is varying with the magnitude while the imaginary part is the phase. In the bode diagram,

$$\text{HdB} = 20\log_{10}H \quad (3)$$

magnitude is plotted in decibels (dB) with respect to frequency and phase, φ is plotted in degrees with respect to frequency.

For simulation of electronic circuits ORCAD-PSpice program is usually employed. In the literature, there are many studies realized with ORCAD-PSpice[11-23]. In this study ORCAD-PSpice program is employed to evaluate performance of the Bode results obtained from LabVIEW.

The setup of the paper is as follows: gain and phase difference calculation is presented in Section 2; plots of real time bode diagrams in LabVIEW that is obtained with NI myDAQ [24] for LPF, HPF, differentiator and integrator circuits and ORCAD-PSpice simulation of those circuit is given in Section 3; limitations of real time measurement application is given in Section 4 and conclusion is given in the last section.

2. GAIN AND PHASE DIFFERENCE CALCULATION

In the experiments the input signal, which is a sinusoidal, is generated by NI myDAQ. Input signal's frequency sweep is done between the frequency values specified by the user in the front panel of the LabVIEW.

Gain, in electronics circuit, can be calculated as dividing the amplitude of the output signal by the amplitude of the input signal. Gain calculation in LabVIEW is given in Figure 1.

$$\text{Gain} = A = \frac{V_{out}}{V_{in}} \quad (4)$$

Let $\sin(\omega t)$ be the input signal and then the output equals to $A\sin(\omega t + \varphi)$. Here ω is the angular frequency, A is the gain of the circuit and φ is the phase of the output signal.

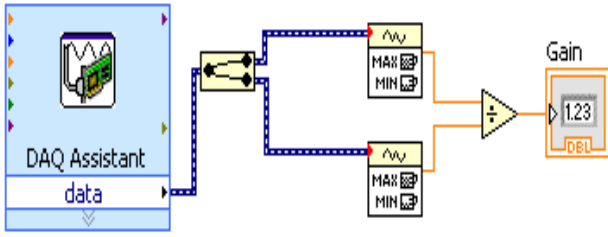


Figure 1. Block diagram for calculation of the gain of the circuit

The block code for calculation of phase difference is given in Figure 2. For the calculation of the phase difference between the input and the output signals, the input signal is multiplied with the gain to level the amplitudes of both the input and output signals as a first step. Then, the resulting signal, $Asin(\omega t)$, is subtracting from the output signal. By applying trigonometric conversion:

$$Asin(\omega t) - Asin(\omega t + \varphi) = 2A(\cos(\omega t + \frac{\varphi}{2}) \sin(-\frac{\varphi}{2})) \tag{5}$$

here the resulting signal is a sinusoidal, $\cos(\omega t + \frac{\varphi}{2})$, and the amplitude of the signal in equation 5 equals to $2A|\sin(-\frac{\varphi}{2})|$. If we divide the amplitude of the difference signal by two times of the gain ($2A$), we obtain the sine of the half of the phase difference ($\varphi/2$) between the input and output signals and by taking the inverse sine (arcsine) of this value we obtain the half of phase difference ($\varphi/2$). Normally, the arcsine function returns values between $-90 \leq \varphi/2 \leq 90$ degrees, but since we get the absolute value of the $\sin(-\frac{\varphi}{2})$, the arcsine function returns values

between $0 \leq \varphi/2 \leq 90$, thus the phase difference is between $0 \leq \varphi \leq 180$ degrees. Hence, we can obtain phase difference between the input and output signals, but we cannot decide whether the output signal is lagging or leading.

To determine whether the output signal is lagging or leading, we multiply the output signal with the signal that is the input signal multiplied with gain of the circuit, A.

$$Asin(\omega t)Asin(\omega t + \varphi) = 0.5A^2(-\cos(2\omega t + \varphi) + \sin(-\varphi)) \tag{6}$$

The resulting signal in equation 6 is a sinusoidal with an offset value, $(A^2 \sin(-\varphi))/2$. If we obtain the offset value of the signal in equation 6, we can decide the output signal of the circuit whether lagging or leading. The offset value is positive means φ degree is negative that is between -180 and 0 degrees, the output is lagging, and the offset value is negative means φ degree is positive that is between 0 and 180 degrees, the output is leading.

Let V_m and V_{off} be the amplitude and offset value of a sinusoid, respectively. The maximum value of this sinusoid is $V_m + V_{off}$ and the minimum value of the sinusoid is $V_{off} - V_m$. To calculate the offset of the signal in equation 6, the maximum ($V_m + V_{off}$) and the minimum ($V_{off} - V_m$) values of the signal added together $((V_m + V_{off}) + (V_{off} - V_m) = 2 V_{off})$ and then, this value is divided by two.

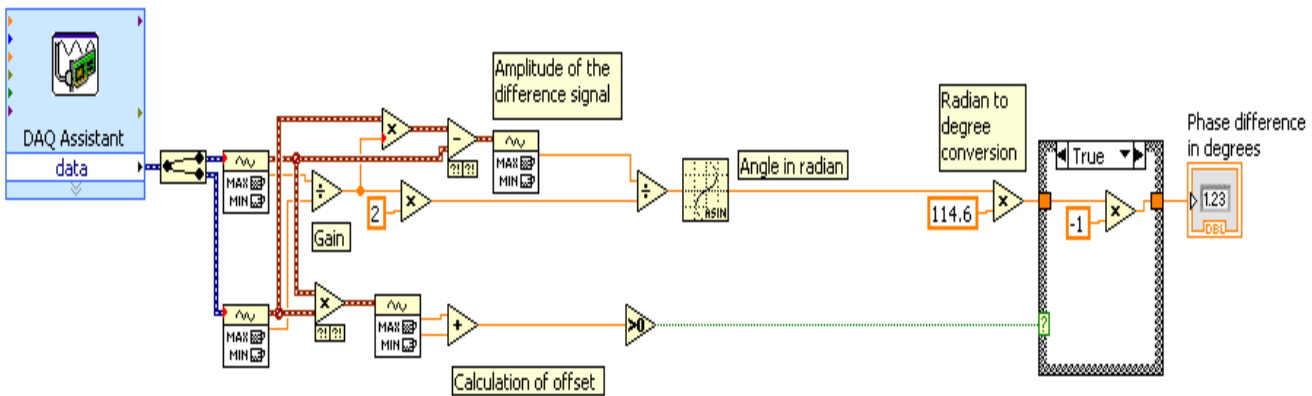


Figure 2. The block diagram for calculation of phase difference

3. MEASUREMENT & SIMULATION RESULTS

In the experiment, the bode diagrams of four different circuits are being plotted. These circuits are passive low pass (LPF) and high pass(HPF) filter, Op-amp differentiator and integrator amplifier circuits. The experimental setup is shown Figure 3.

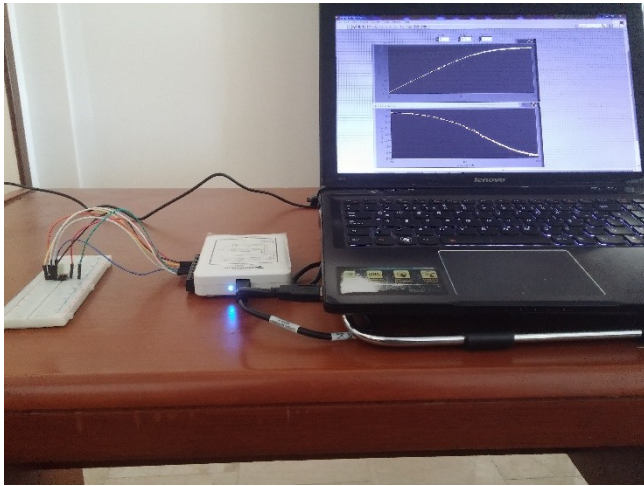


Figure 3. The real-time experimental setup

3.1. The results for passive LPF

The circuit for the Low Pass Filter (LPF) can be seen in Figure 4, the value of the resistor is 1k ohm and the value of the capacitor is 0.82uF. The cut-off frequency of the circuit, ω_c , is about 194 Hz.

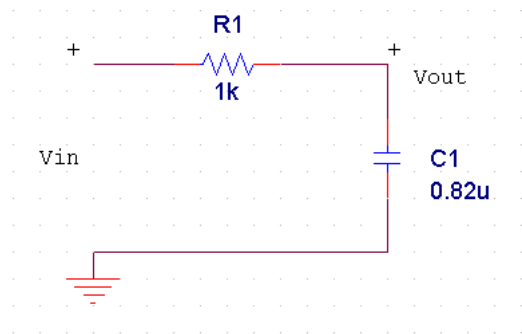


Figure 4. The circuit for LPF

The simulation result can be seen in Figure 5 and the measurement result can be seen in Figure 6.

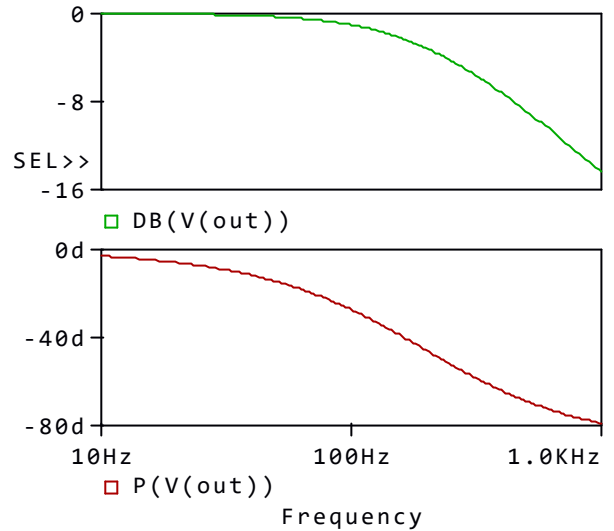


Figure 5. The simulation result of the LPF circuit

The cut-off frequency ω_c is about 195 Hz and the phase difference is -45 degrees at the cut-off frequency in the simulation. In the measurement, the cut-off frequency ω_c is near 200 Hz and the phase difference at this frequency is also near -45 degrees.

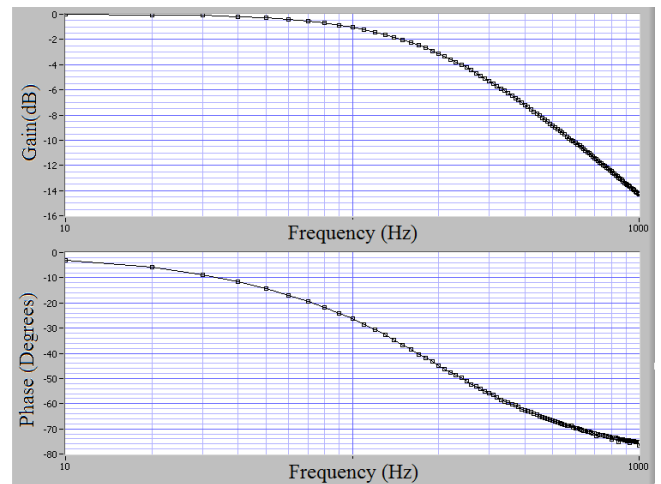


Figure 6. The measurement result of the LPF circuit

3.2. The results for passive HPF

The circuit of the High Pass Filter (HPF) is given in Figure 7. The cut-off frequency ω_c is again about 194 Hz, since we use same resistor and capacitor as in the LPF circuit.

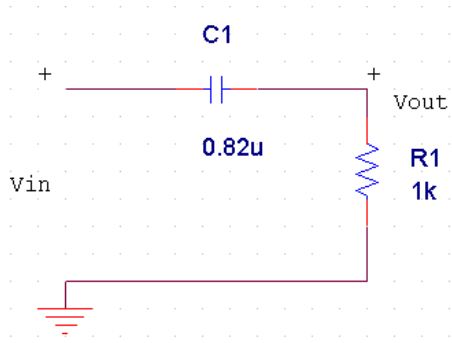


Figure 7. The circuit for HPF

The simulation result for the HPF circuit is given in Figure 8 and the measurement result is given in Figure 9.

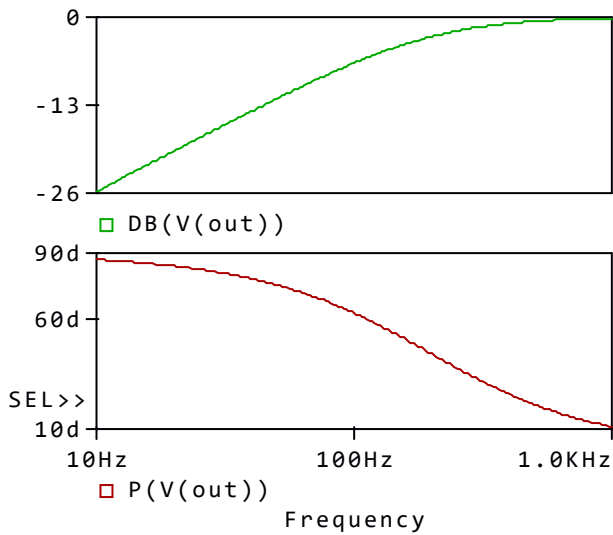


Figure 8. The simulation result of the HPF circuit

The cut-off frequency ω_c is about 195 Hz and the phase difference is 45 degrees at the cut-off frequency in the simulation.

In the measurement, the cut-off frequency ω_c is near 200 Hz and the phase difference at this frequency is also near 45 degrees.

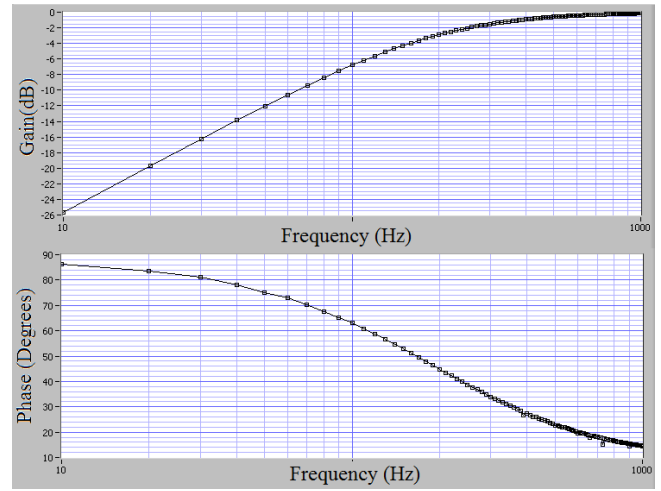


Figure 9. The measurement result of the HPF circuit

3.3. The results for Op-amp differentiator circuit

The differentiator circuit is given in Figure 10. The cut-off frequency of the circuit is about 194 Hz and the gain of the circuit is 2.2 V/V (6.85 dB).

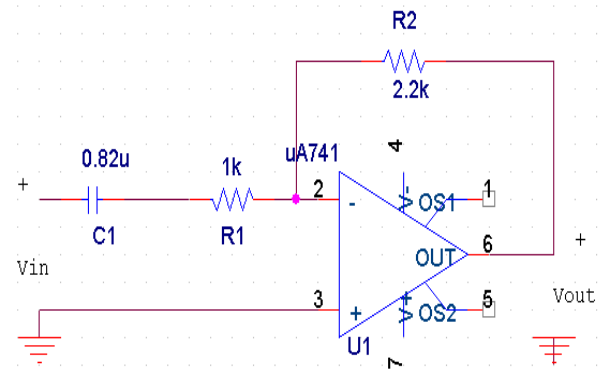


Figure 10. Op-amp differentiator circuit

The simulation result is given in Figure 11. In the simulation, the cut-off frequency is near 190 Hz, the gain is about 6.7 dB and the phase difference

is about - 135 degrees. The measurement result for the differentiator circuit is given in Figure 12.

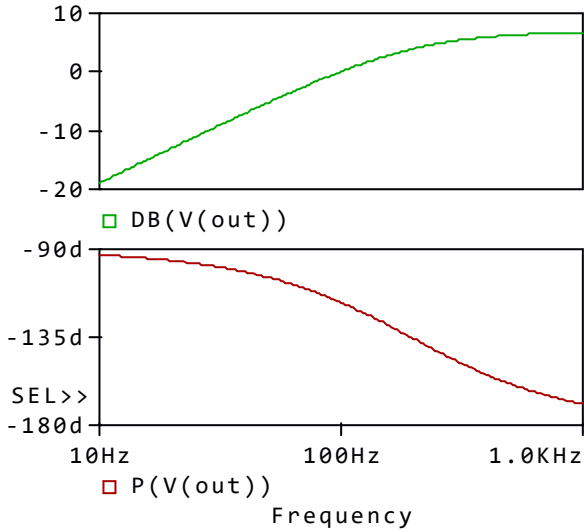


Figure 11. The simulation result for the differentiator circuit

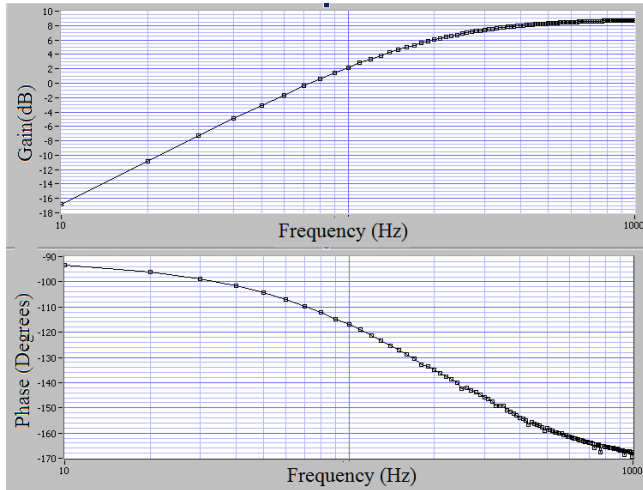


Figure 12. The measurement result for the differentiator circuit

In the measurement the gain is about 8.6 dB (2.69V/V), the cut-off frequency is about 200 Hz and the phase difference at the cut-off frequency is -135 degrees.

3.4. The results for Op-amp integrator circuit

The integrator circuit is given in Figure 13. The bandwidth of the circuit is about 88 Hz and the gain of the circuit is 2.2 V/V (6.85 dB).

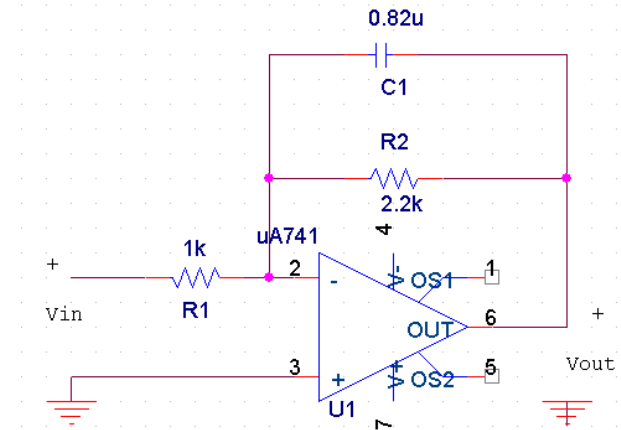


Figure 13. The Op-amp integrator circuit

The simulation result for this circuit is given in Figure 14. According to the simulation results, the cut-off frequency is 88 Hz, the phase difference at the cut-off frequency is 135 Hz and the gain is 6.8 dB (2.18 V/V).

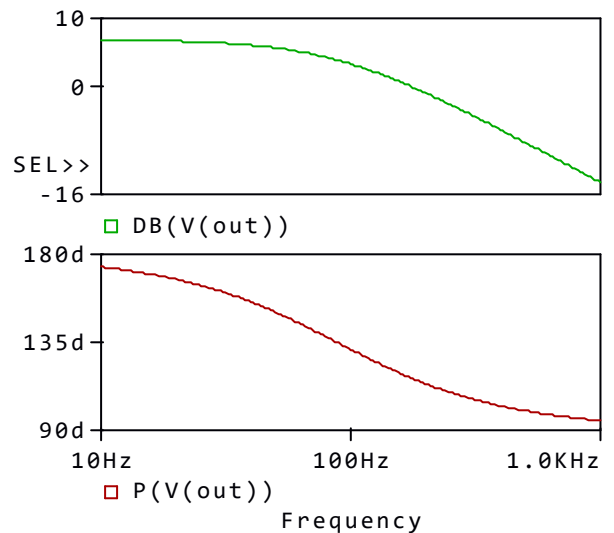


Figure 14. The simulation result for the integrator circuit

The measurement result for the integrator circuit is given in Figure 15. As it can be seen in the Figure, the cut-off frequency is about 75 Hz , the phase difference at the cut-off frequency is 135 degrees and the gain is about 8.5dB (2.66 V/V).

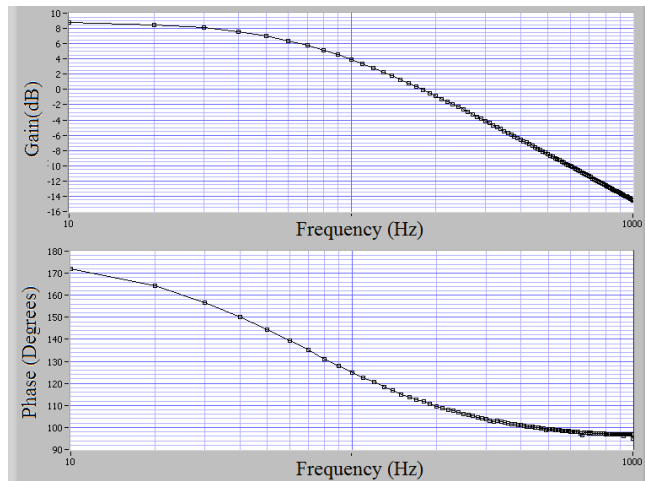


Figure 15. The measurement result for the integrator circuit

4. MEASUREMENT LIMITATIONS

There are two main limitations for measurement: analog input range and the sampling rate of the Data Acquisition (DAQ) card.

The amplitude of the output signal of the circuit must be within the boundaries of the analog input range of the DAQ card.

The other important limitation factor is the sampling rate. According to the Nyquist theorem, a signal must be sampled with at least two times of the highest frequency present in the signal (Nyquist frequency), to capture all the information the signal possesses. However, in the frequency domain, the sampling rate must more than twice of the signal's highest frequency component for practical reason and preferably between five and ten times of it. If the signals are sampled with 10 times of its highest frequency component, the sampled signals are a reasonable approximation of the original signals [25, 26].

The analog input range of the NI-myDAQ card, the DAQ card that is used in the experiment, is between -10V and 10V and the sampling rate of it is 200kS/s. Since the DAQ card is multiplexed DAQ card, the sampling rate for the one analog channel is 100kS/s. Thus, the experiment is setup such that the amplitude of the output signal is less than 10V and, the end frequency of the bode plot is 1 kHz since we sample the signals with 10 times of its highest frequency component.

5. CONCLUSION

The real time bode diagram of the electronic circuits are successfully plotted in LabVIEW without using special VIs (virtual instruments) such that SI Bode Plot VI. For the gain calculation four operations and logarithmic operation is used while for the phase difference calculations four operations and trigonometric operations are used. Hence, with same algorithm real time Bode diagram of the circuits can be plotted in MATLAB or in other programming languages like C.

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