Simple and Accurate Frequency to Voltage Converter

A. Lorsawatsiri[1], W. Kiranon[1], V. Silaruam[2], W. Sangpisit[1], and P. Wardkein[1]

[1] Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang
Ladkrabang, Bangkok 10520, THAILAND
Tel. (662)326411 Ext. 3340, Email: s0060024@kmitl.ac.th, anuree@mut.ac.th
[2] Department of Telecommunication Engineering, Mahanakorn University of Technology
Nong Chok, Bangkok 10530, THAILAND

Abstract- **A new technique has been developed for frequency to voltage converter. This technique, based on a very simple operating principle, comprises a differentiator, two RMS-DC converters, and a divider. The proposed converter provides an accurate output and a linear transfer characteristic. Moreover, its output response has input-amplitude independent characteristic. The performance of this converter is evaluated by computer simulation. The simulation results are in good accordance with the theoretical analyses.**

I. Introduction

Frequency to voltage or current converter is a device that generates an output voltage or current proportional to the frequency of a sinusoidal input signal. It has many applications in power control, communication, instrumentation and measurement systems, etc. The most known techniques used for frequency to voltage or current conversion are generally based on low-pass filtering of fixed duration at a rate set by the input frequency or counting the number of narrow pulses over a fixed period time [1-9]. Even though these techniques are widely used, they are based on complex circuits. Moreover, some of those have to use one or more reference signals with a very much higher frequency than the input signal.

Other mentioned techniques are based on simple analog circuits. They are proposed by taking advantage of the mathematical characteristic of sinusoidal signals [10-11]. The frequency to voltage converter in [10] is realized by a differentiator, an integrator, a divider and a square-rooter. However, the division of the differentiator output to the integrator output causes large spikes when an initial value of the integrator is not zero. Recently, the other simple technique is proposed in [11]. Unlike the converter in [10], it does not generate spikes. Unfortunately, an initial value of the integrator affects the converted output. Thus uncertain integral initial value makes the output of this technique inaccurate.

In this paper, a new simple frequency to voltage converter is presented. It employs no additional integrators comparing to the previous converter. So the integral initial value which influences the converted output as in [11] will not occur in the proposed converter. In other words, the proposed technique provides much better accuracy than the previous technique. The computer simulations are conducted to confirm this idea and to illustrate the performances of the proposed frequency to voltage converter.

II. The Proposed Frequency to Voltage Converter

A. Basic Principle

A new frequency to voltage converter (FVC) is presented. It is composed of a differentiator, two RMS-DC converters, and a divider. The block diagram of the proposed system is shown in Fig. 1. Assuming that the input signal is a pure sinusoidal signal with a peak amplitude of A and input frequency of ω_{in},

$$v_{in}(t) = A\sin(\omega_{in} t). \tag{1}$$

Then, the derivative of this signal at the output of the differentiator can be written as

$$v_d(t) = A\tau_d\omega_{in}\cos(\omega_{in} t), \tag{2}$$

where τ_d is the time constant of the differentiator.

Feeding $v_{in}(t)$ and $v_d(t)$ into the RMS-DC converters yields the results as

$$V_{RMS1} = \frac{A}{\sqrt{2}} \tag{3}$$

and

$$V_{RMS2} = \frac{A\tau_d\omega_{in}}{\sqrt{2}}, \tag{4}$$

respectively.

Thus dividing V_{RMS2} in (4) by V_{RMS1} in (3) yields

$$V_{out} = k\omega_{in}, \tag{5}$$

where $k = k_{div}\tau_d$ is the sensitivity of the converter and k_{div} is the scaling factor (gain) of the divider.

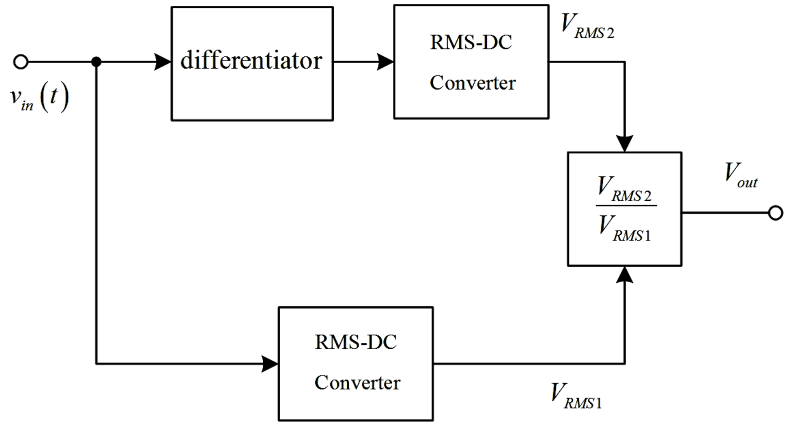

Fig. 1. Basic principle of the proposed frequency to voltage converter.

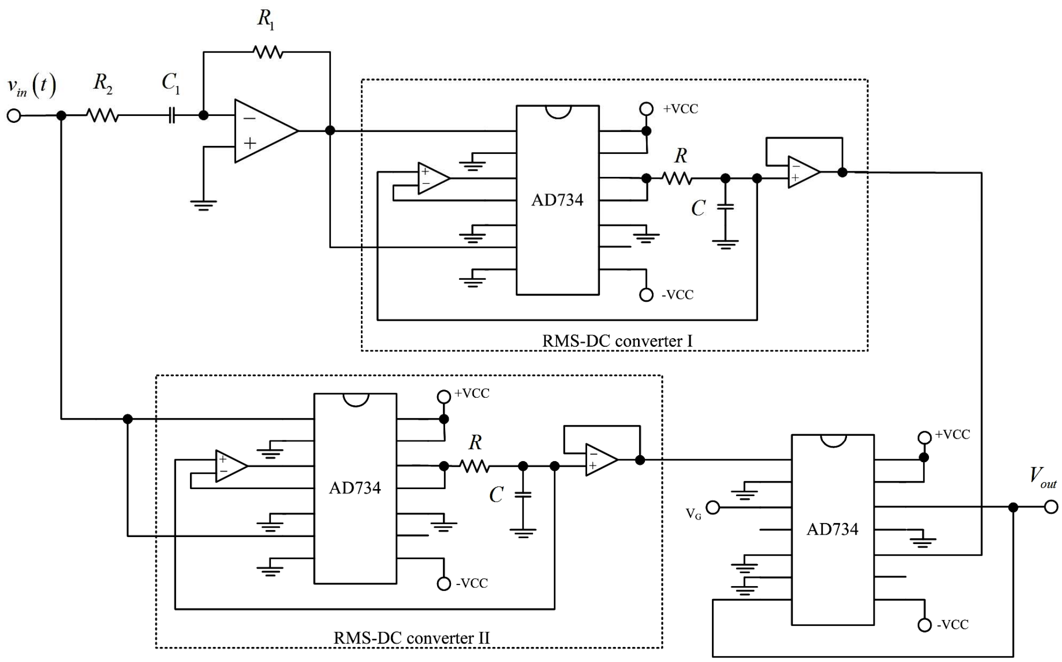

Fig. 2. Schematic diagram of the proposed frequency to voltage converter.

It is clearly seen from (5) that the output signal is linearly proportional to the input frequency, ω_{in}, and insensitive to the input signal amplitude, A.

B. *Hardware Implementation*

As an example, a prototype hardware can be implemented as shown in Fig. 2. In this implementation, five operational amplifiers and three analog multipliers are used. One of the operational amplifiers is used for performing the differentiator. The time constant of the differentiator, τ_d, can be set by adjusting the resistor, R_1, and/or the capacitor, C_1, values. Other operational amplifiers are connected with multipliers to realize RMS-DC converters, as shown in the dash boxes of Fig. 2. The last multiplier is used as a divider. The V_G voltage is employed for adjusting the scaling factor, k_{div}, of the divider.

From Fig. 2, the input signal, $v_{in}(t)$, is sent to two paths. One is fed to the differentiator and then sent to the RMS-DC converter I; therefore, the output signal as shown in (4) is implemented. The other is fed to the RMS-DC converter II to carry out the output signal as expressed in (3). Next, those outputs are sent to the divider to manipulate a DC voltage that represents the frequency of sinusoidal input signal as the output of the FVC.

III. Simulation Results

To illustrate the significance of theoretical results obtained in the preceding section, the simulations have been carried out using both MATLAB/Simulink and SPICE simulation programs.

In the MATLAB simulation, the FVC based on the proposed technique in Fig. 1 and the FVC based on the technique in [11] are simulated where the sensitivities of both FVCs are set to 1.299 mV/Hz. To compare their performances, those FVCs are tested in two conditions. In the first condition, the integral initial value is set to zero. Then apply a 1000 Hz sinusoidal signal depicted in the upper frame of Fig. 3 to both circuits. The obtained results are shown in the lower frame of the same figure. It is clear that the results from both FVCs agree with the theoretical one.

However, in the second condition that the inherent integral initial value is indispensable, the results of both FVCs for a 1000 Hz sinusoidal signal differ markedly as shown in Fig. 4. These results show that the proposed technique produces more significantly accurate output responses. Additionally, they support the hypothesis about the effect of integral initial value that is mentioned in the introduction section.

SPICE simulations are also performed to investigate the feasibility of the proposed FVC in Fig. 2. The differentiator is simulated using the schematic implementation in [12] with LF356 operational amplifier. AD734 analogue multipliers are used as the RMS-DC converters and the divider. The FVC based on the principle in [11] is also simulated for comparison purposes where LF356s and AD734s are used.

First, a 1000 Hz cosine wave signal with amplitude of 1 V as shown in the upper frame of Fig. 5 is applied to both circuits. The outputs are obtained as illustrated in the lower frame of Fig. 5. It is seen that in this case the initial value of the integrator is none; then, both circuits correctly detect the input frequency.

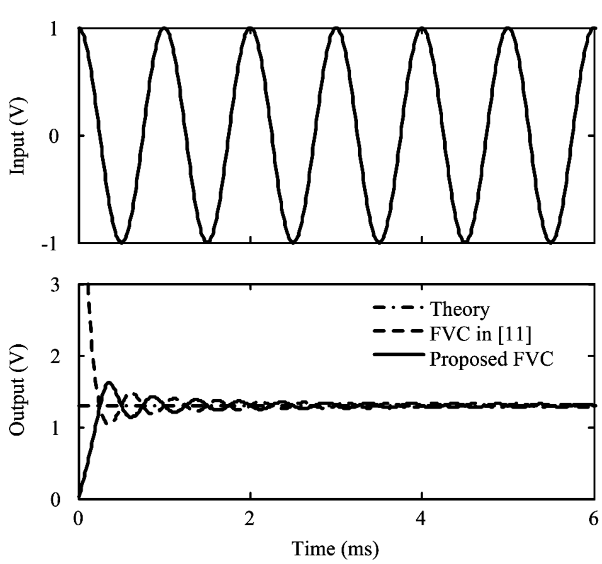

Fig. 3. MATLAB simulation results for a 1000 Hz sinusoidal signal.

Next, let the initial phase of the input signal are 30° shifted, the outputs are carried out as demonstrated in Fig. 6. It shows that the output from the proposed circuit in Fig. 2 is still very close to the theoretical result while output from [11] has an error phenomenon similar to the MATLAB simulation result. The transfer characteristic of the proposed FVC is investigated by varying the input frequency while the peak amplitude is kept constant at 1 V. The linearity of the resultant characteristic is shown in Fig. 7. It confirms that the proposed circuit provides a linear relationship between input frequency and output voltage. To demonstrate the input-amplitude independent characteristic, the sinusoidal signals at 1000 Hz with varying amplitude from 1 V to 10 V are applied to the FVC. It yields the result as shown in Fig. 8. It is obvious that the characteristic is significantly flat as expected.

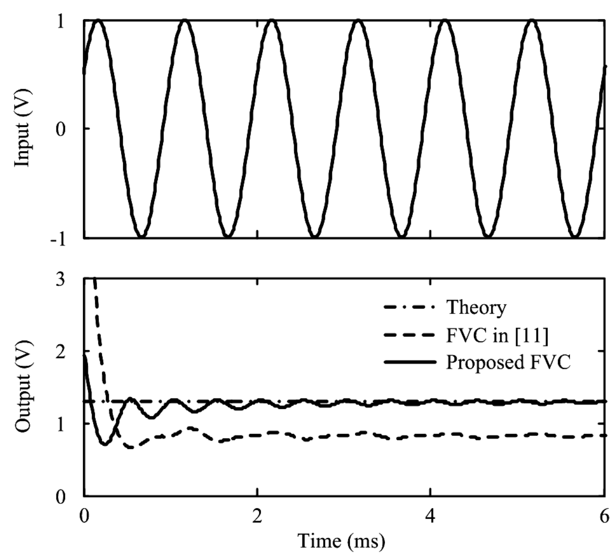

Fig. 4. MATLAB simulation results for a 1000 Hz sinusoidal signal with integral initial value.

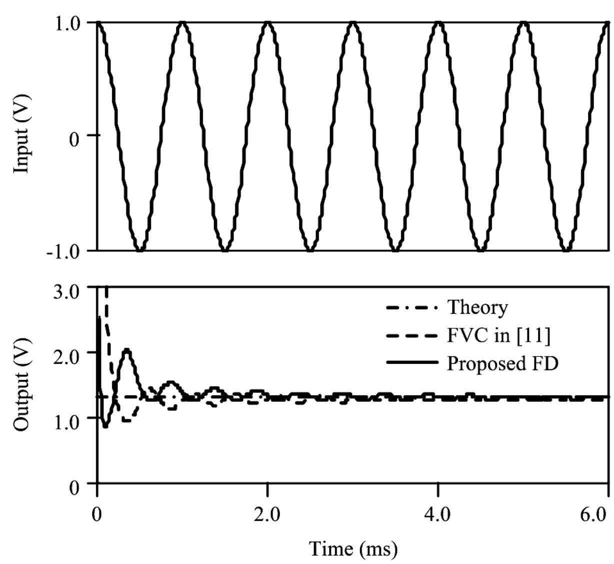

Fig. 5. Output from the circuit in Fig. 2 in comparison with [11].

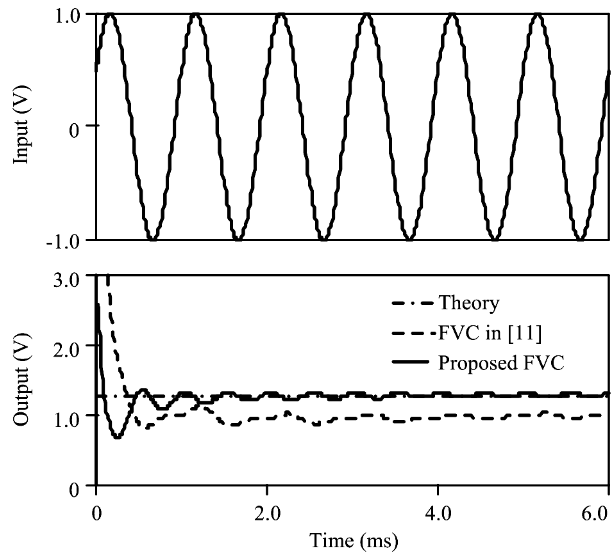

Fig. 6. The effect of integral initial value on the outputs of FVCs.

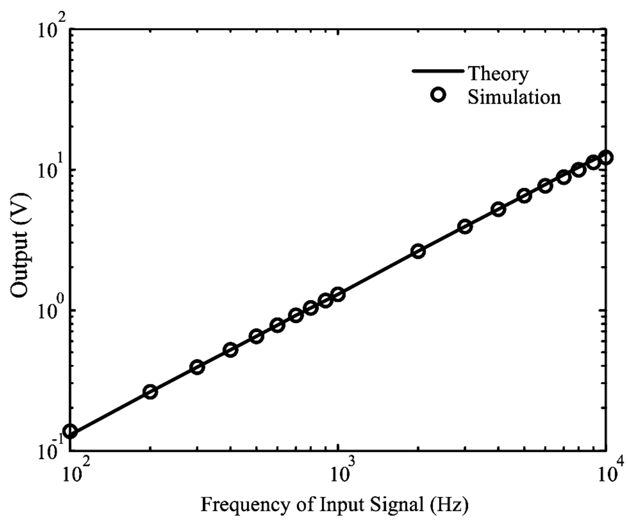

Fig. 7. Transfer characteristic of the proposed FVC.

IV. CONCLUSION

This paper has presented a new technique of frequency to voltage converter. It is composed of a differentiator, two RMS-DC converters, and a divider. Since no additional integrators are exploited, it is superior to the FVC proposed in [11] because of no initial value effect. The proposed FVC provides both accurate measurements and simple circuit configuration. Its performances using available commercial devices are tested by SPICE simulation. The simulation results are in significant agreement with the theoretical

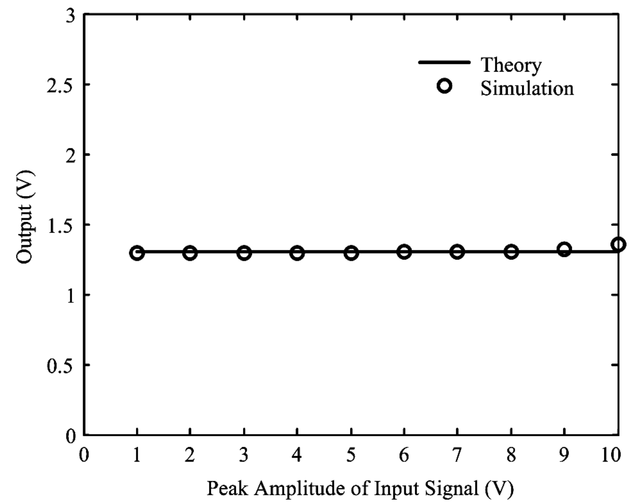

Fig. 8. Amplitude independent characteristic of the proposed FVC.

results. It is found that the obtained output is linearly proportional to an input frequency. Moreover, the detected characteristic is independent of input amplitude.

REFERENCES

[1] T.L. Floyd and D. Buchla, *Basic Operational Amplifiers and Linear Integrated Circuits*. New Jersey: Prentice-Hall Inc., 1999, pp.450-457.

[2] A.B. Grebene, *Bipolar and MOS Analog Integrated Circuits Design*. New Jersey: John Wiley, 2003, pp.615-624.

[3] A.S. Hou, "Design of fast frequency-to-voltage converter using successive-approximation technique," *Int. J. Electron*., vol. 92, pp. 635-644, Nov. 2005.

[4] M.K. Mahmood and J.E. Allos, "Fast frequency detection of sinusoidal signals," *Int. J. Electronics*., vol. 54, No. 6, pp. 825-832, 1983.

[5] M.K. Mahmood, J.E. Allos, and M.A.H. Abdul-karim, "Microprocessor implementation of a fast and simultaneous amplitude and frequency detector for sinusoidal signals," *IEEE Trans. Instrum. Meas.*, vol. 34, no. 3, pp. 413-417, 1985.

[6] H.T. Bui and Y. Savaria, "High-speed differential frequency to voltage converter," in *Proc. IEEE North East Workshop Circuits Syst.,* 2005, pp. 373-376.

[7] A. Djemouai, M.A. Sawan, and M. Slamani, "New frequency-locked loop based on CMOS frequency-to-voltage converter: Design and implementation," *IEEE Trans. Circuits Syst. II Analog Digit. Signal Process,* vol. 48, pp. 441-449, 2001.

[8] W. Kiranon, P. Wardkein, and C. Loescharataramdee, "Simple frequency/voltage convertor with low output ripple," *Electron. Lett.*, vol. 27, pp. 205-206, 1991.

[9] H.T. Bui and Y. Savaria, "Design of a high-speed differential frequency-to-voltage converter and its application in a 5-GHz frequency-locked loop," *IEEE Trans. Circuits and Syst. I*, vol. 55, pp. 766-774, 2008.

[10] W. Surakampontorn, Y. Chonbodeechalermroong, and S. Bunjongjit, "An analog sinusoidal frequency-to-voltage converter," *IEEE Trans. Instrum. Meas.*, vol. 40, pp. 925-929, Dec. 1991.

[11] T.Y. Lin, E.M. Drakakis, and A.J. Payne, "Architecture for frequency-to-current conversion," *Electron. Lett*., vol. 37, pp. 1427-1428, Nov. 2001.

[12] A.S. Sedra and K.C. Smith, *Microelectronic Circuits*. New York: Oxford University Press, 1991.