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VARIABLE VOLTAGE TO CURRENT
CONVERSION CIRCUIT

The present invention relates generally to a variable voltage to current conversion circuit, and more particularly but not exclusively, to a variable voltage to current conversion circuit for suitable for use in an active filter.

Conventional filters for use in electrical circuits such as filters are typically constructed in LC circuits by using inductor and capacitor elements. In recent years, a miniaturization of circuits has been increasingly demanded, with the advancement of integrating technology. To cope with such a demand, an active filter possible to be incorporated in such an integrated circuit has been developed. In order to construct this type of filter, a filter time constant must be set using a resistance and a capacitance. However, devices which define the time constant are not sufficiently precise in the interior of an IC. Therefore, an accuracy of the time constant is increased by making a current flowing through the devices, etc., variable. As a circuit which is most effective for varying the current, there is known a voltage to current conversion circuit called as Gilbert cell or a Gilbert circuit.

FIGURE 1 shows a typical example of a variable voltage to current conversion circuit using the Gilbert

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cell.

In FIGURE 1, differentially related voltages V_1 and V_2 are supplied to input terminals 11 and 12, respectively. The input terminals 11 and 12 are connected to the bases of differentially paired transistors Q1 and Q2. The collector of the transistor Q1 is connected to a power line V_{cc} , while its emitter is connected to the connection node of the collector and the base of a diode-fashion transistor Q3 and also to the base of a transistor Q5, through a resistor R11.

The collector of the transistor Q2 is connected to the power line V_{cc} , while its emitter is connected to the connection node of the collector and the base of a diode-fashion transistor Q4 and also to the base of a transistor Q6, through a resistor R12. The emitters of the transistors Q3 and Q4 are grounded commonly through a current source I11. Also the connection node of the emitters of the transistors Q5 and Q6 is grounded through a current source I12. The collector of the transistor Q5 is connected to the power line V_{cc} . While the collector of the transistor Q6 is connected to the power line V_{cc} , and also to an output terminal 13.

In the variable voltage to current conversion circuit as described above, a differential input is given by V_{in} ($V_{in} = V_1 - V_2$). A current flowing through the transistor Q1 is given by i_1 . A current flowing through the transistor Q2 is given by $-i_1$. Further, a current flowing through the



transistor Q5 is given by i_2 . A current flowing through the transistor Q6 is given by $-i_2$. And a potential difference ΔV between the bases of the transistors Q5 and Q6 will be in the relation shown by the following equation:

$$\begin{aligned}\Delta V &= V_t \cdot \log-n \left[\frac{i_{11}}{2} + i_1 \right] / i_s \\ &\quad - V_t \cdot \log-n \left[\frac{i_{11}}{2} - i_1 \right] / i_s \\ &= V_t \cdot \log-n \left[\frac{i_{12}}{2} + i_2 \right] / i_s \\ &\quad - V_t \cdot \log-n \left[\frac{i_{12}}{2} - i_2 \right] / i_s \quad \dots (1)\end{aligned}$$

In the equation (1), the V_t is a thermal voltage constant, the i_s is a transistor saturation current having the same value over all transistors. Under the balanced state ($\Delta V = 0$), currents i_{11} and i_{12} supplied from the current sources I_{11} and I_{12} differentially flow by each the 1/2 of the total currents. From the equation (1), the current i_2 given as the following equation (2).

$$i_2 = (i_{12}/i_{11})i_1 \quad \dots (2)$$

On the other hand, when the equivalent emitter resistances of the transistors Q1, Q2, Q3 and Q4 are all given as r_e , the current i_1 is obtained from the following equation.

$$i_1 = V_{in} / (r_{11} + r_{12} + 4r_e) \quad \dots (3)$$

In the equation (3), the r_{11} and r_{12} represent the resistance of the resistors R_{11} and R_{12} . Also the r_e represents the emitter resistance of the transistors. From the equations (1) and (2), the current i_2 is given by the following equation.



$$i_2 = V_{in}/\{(r_{11} + r_{12} + 4r_e)(i_{11}/i_{12})\} \quad \dots (4)$$

This will become almost an output current. As seen from the equation (4), to vary the resistance component $(r_{11} + r_{12} + 4r_e)(i_{11}/i_{12})$ constituting the filter time constant using a voltage to current converter, it is possible by changing the current i_{12} of the current source I_{12} .

In the circuit described above, the transistors Q3 through Q6 comprise a Gilbert cell and this Gilbert cell is ideally used as a convenient current converter as shown in equation (2). However, there are such large problems that as P-N junction logarithmic compressed voltage by the transistors Q3 and Q4 was exponentially expanded by the transistors Q5 and Q6, it is largely affected by characteristics of semiconductors, mixing of noise is unavoidable and DC balance is bad. In particular, when composing an active filter, an S/N ratio is deteriorated largely as signal must go through this type of circuit by the amount of that exponent. The smaller a signal level is, the more this phenomenon becomes disadvantageous. On the contrary, however, when a signal level is increased, distortion will increase as a gap between a logarithmic and exponential correction comes to appear intensely.

When signal is passed through a voltage to current converter which uses a Gilbert cell as described above, S/N ratio is deteriorated, and also DC balance is deteriorated too.



The present invention therefore seeks to provide a variable voltage to current conversion circuit which is capable of largely reducing characteristic deterioration caused by a Gilbert cell.

5 According to the present invention there is provided a variable voltage to current conversion circuit comprising a voltage to current converter, a gain controllable current converter coupled to the voltage to current converter and an adder coupled to
10 the voltage to current converter and the gain controllable current converter.

 In an advantageous embodiment of the invention the voltage to current convertor has first and second transistors supplied with differentially related
15 voltages, a diode-fashion third transistor connected to the first transistor through a first resistor, a diode-fashion fourth transistor connected to a second transistor through a second resistor, and a first current source coupled to the third and the fourth
20 transistors, the gain controllable current converter has the diode-fashion third transistor, the diode-fashion fourth transistor and the first current source which are shared with the voltage to the current converter, and a fifth and a sixth transistors
25 connected to the third and fourth transistors and to a second current source, and the adder has a third current source coupled to the second and the sixth transistors. According to the above construction, an output current from the output section is composed of a
30 signal component passing through a path having characteristics of a



logarithmic compression and an exponential expansion by semiconductor characteristics, and a signal component simply current-converted through the collector of the second transistor. Thus the deterioration of the signal component experienced the logarithmic compression and the exponential expansion may be decreased.

For a better understanding of the present invention and many of the attendant advantages thereof reference will be now be made by way of example to the accompanying drawings, wherein:

FIGURE 1 is a circuit diagram showing a conventional variable voltage to current conversion circuit;

FIGURE 2 is a circuit diagram showing a preferred embodiment of the present invention; and

FIGURE 3 is a block diagram representation of the circuit as shown in FIGURE 2.

Referring now to FIGURES 2 and 3, a preferred embodiment of the variable voltage to current conversion circuit according to the present invention will be described in detail. FIGURE 2 shows a preferred embodiment of the present invention, while FIGURE 3 shows a block diagram representation of the circuit of FIGURE 2.

In FIGURE 2, input terminals 21 and 22 are supplied with differentially related voltages V_1 and V_2 . The input terminals 21 and 22 are connected to the bases of a differentially paired transistors Q21 and Q22. The



transistor Q21 has its collector connected to a power line Vcc, and also its emitter to the connection node of the collector and the base of a diode-fashion transistor Q23 and to the base of a transistor Q25 through a resistor R21. The transistor Q22 has its collector connected not only to the power line Vcc through a current source I23 but also to an output terminal 23. The emitter of the transistor Q22 is connected to the connection node of the collector and the base of a diode-fashion transistor Q24 and also to the base of a transistor Q26, through a resistor R22. The emitters of the transistors Q23 and Q24 are grounded commonly through the current source I21. Also the emitters of the transistor Q25 and Q26 are grounded commonly through a current source I22. The collector of the transistor Q25 is connected to the power line Vcc, while the collector of the transistor Q26 is connected to the collector of the transistor Q22.

The circuit described above is represented by a block diagram as shown in FIGURE 3. A section composed of the transistors Q21, Q23, Q24 and Q22 forms a voltage to current converter 31, a section composed of the transistors Q23, Q25, Q26 and Q24 forms a current converter 32, and the connection node of the collectors the transistors Q26 and Q22 forms an adder 33.

In this circuit, a current i_{23} supplied from the current source I23 is set at $i_{23} = (i_{21} + i_{22})/2$. When assuming that a current flowing through the transistor Q21



is $i1'$, a current flowing through the transistor Q25 is $i2'$, and the differential input is given by V_{in} ($V_{in} = V_1 - V_2$), the following equations are obtained from the above equations (2) and (3).

$$i2' = (i22/i21)i1' \quad \dots (5)$$

$$i1' = V_{in}/(r21 + r22 + 4r_e) \quad \dots (6)$$

An output current I_{out} at this time is expressed as follows;

$$\begin{aligned} i_{out} &= i1' + i2' \\ &= \{1 + (i22/i21)\}\{V_{in}/(r11 + r12 + 4r_e)\} \dots (7) \end{aligned}$$

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Therefore, a resistance component, i.e., an element of the filter time constant can be adjusted through the adjustments of the currents supplied by the current sources.

Though a variable range becomes narrow since the equation (7) contains fixed terms, a narrower variable range is rather advantageous for the purpose of correcting the dispersion of the filter time constant.

Now the operation of this circuit will be described in comparison with the conventional circuit.

To obtain a constant which makes the mean value of the time constant equal to that of the conventional circuit, it is sufficient when $i2 = i_{out}$ is valid in the relation between the equations (5) and (7). When the resistance r_e is sufficiently smaller than the resistances $r21$ and $r22$ and the resistances $r21$ and $r22$ are equal to those of the



resistors R11 and R12 in the conventional circuit, as shown in FIGURE 2, the mean value of the time constant will become the same as that of the conventional circuit from the following equation.

$$(i_{12}/i_{11})r_{21} = \{1 + (i_{21}/i_{22})\}r_{11} \quad \dots (8)$$

Here, a case where $i_{11} = i_{12}$ and $i_{2'} = (1/3)i_{1'}$ are valid between the currents will be considered. In this case, the r_{21} becomes equal to $(4/3)r_{11}$. In order to make the input dynamic range equal to that of the conventional circuit, the $i_{1'}$ should be made equal to $(3/4)i_{11}$. The sum of the currents of the current sources in the conventional circuit is given by $i_{11} + i_{12} = 2i_{11}$, while in the circuit of this embodiment the sum of the currents of the current sources are given by $i_{21} + i_{22} - (4/3)i_{21} = i_{11}$. That is, even when the dynamic range is made equal to that of the conventional circuit, the sum of the currents of the current sources is reduced to a half of that of the conventional circuit. This is because that the collector current of the transistor Q22, which is not used in the conventional circuit, is effectively utilized in the embodiment. This collector current of the transistor Q22 is simply converted from the input voltage. On the other hand, the original output of the Gilbert cell presents on the collector of the transistor Q22 after experienced the operations of the logarithmic compression and the exponential expansion. This current component contains a noise caused by semiconductor



characteristics, resulting in deterioration of the S/N ratio as described for the conventional circuit. In this circuit, however, the output current i_{out} is not composed of only the output of the Gilbert cell, but contains the output due to the simple voltage to current conversion at the transistor Q22. As a result, the signal component deteriorated after the operations of the logarithmic compression and the exponential expansion has been suppressed to the 1/4 of the entire output. The variable range of the output current at this time becomes $\pm (1/4)$, that is, $\pm 25\%$ (the range can be still expanded in the + side) but this is sufficient enough for practical use. Though the output of the Gilbert cell is directly affected by the paired transistors and its DC balance is insufficient, in the case of the circuit of this embodiment the collector current of the transistor Q22 is almost defined by the ratio of the resistances r_{21} and r_{22} and also it is possible to improve its stability. This will be extremely effective, especially when realizing a higher order low pass filter with a DC transmission characteristics.

As described above, the present invention can provide an extremely preferable variable voltage to current conversion circuit without an increase of the number of elements in the circuit configuration. The present invention is also possible to largely reduce the deterioration of the characteristic of the Gilbert cell, and



to improve the noise, the distortion, the DC fluctuation and the deterioration of the signal. Furthermore, the present invention is possible to accomplish a variable voltage to current conversion circuit effective in reducing a current consumption.

While there have been illustrated and described what are at present considered to be preferred embodiments of the present invention, it will be understood by those skilled in the art that various changes and modifications may be made, and equivalents may be substituted for elements thereof without departing from the true scope of the present invention. In addition, many modifications may be made to adapt a particular situation or material to the teaching of the present invention without departing from the central scope thereof. Therefore, it is intended that the present invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out the present invention, but that the present invention include all embodiments falling within the scope of the appended claims.

The foregoing description and the drawings are regarded by the applicant as including a variety of individually inventive concepts, some of which may lie partially or wholly outside the scope of some or all of the following claims. The fact that the applicant has chosen at the time of filing of the present application to restrict the claimed



scope of protection in accordance with the following claims is not to be taken as a disclaimer or alternative inventive concepts that are included in the contents of the application and could be defined by claims differing in scope from the following claims, which different claims may be adopted subsequently during prosecution, for example for the purposes of a divisional application.





CLAIMS:

1. A variable voltage to current conversion circuit comprising a voltage to current converter (31) and a gain controllable current converter (32) coupled to the voltage to current converter (31), CHARACTERIZED IN THAT the conversion circuit further comprises an adder (33) coupled to the voltage to current converter (31) and the gain controllable current converter (32).

2. A variable voltage to current conversion circuit as claimed in claim 1, wherein:

the voltage to current converter (31) has a differentially related input means, a first and a second transistors (Q21, Q22) having bases to be supplied with differentially related voltages from the input means, a diode-fashion third transistor (Q23) having a base and a collector commonly connected to the emitter of the first transistor (Q21) through a first resistor (R21), a diode-fashion fourth transistor (Q24) having a base and a collector commonly connected to the emitter of the second transistor (Q22) through a second resistor (R22), and a first current source (I21) coupled to a connection node of the emitters of the third and the fourth transistors (Q23, Q24)

the gain controllable current converter (32) has the





diode-fashion third transistor (Q23), the diode-fashion fourth transistor (Q24) and the first current source (I21) which are shared with the voltage to current converter (31), and a fifth and a sixth transistors (Q25, Q26) having bases connected to the collectors of the third and the fourth transistors (Q23, Q24), respectively, and emitters commonly connected to a second current source (I22); and

the adder (33) has a third current source (I23) coupled to the connection node of the collectors of the second and the sixth transistors (Q22, Q26), and output means connected to the connection node of the collectors of the second and the sixth transistors (Q22, Q26).

