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PATENT SPECIFICATION

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(54) CURRENT AMPLIFIER

(71) We, PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LIMITED, of Abacus House, 33, Gutter Lane, London, E.C.2., a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

THE INVENTION relates to a circuit arrangement having a constant current amplification and comprising an input current circuit which includes the main current path of a first transistor of one conductivity type and an output current circuit which includes the main current path of a second transistor of the one conductivity type, the base electrodes of the first and second transistors being interconnected, whilst the base electrode currents of these transistors are supplied via the main current path of a third transistor.

Such a circuit arrangement is described, for example, in "International Solid-State Circuits Conference", February 1970, page 156. For example, Figure 1 of the accompanying drawings shows a current amplifier which is included in an operational amplifier and in which the base-emitter paths of the first and second transistors are connected in parallel so that the ensuing current amplification, i.e. the ratio between the output current at the output terminal and the input current at the input terminal, is completely determined by the ratio between the emitter areas of the two transistors.

The base currents required for these two transistors are supplied by the third transistor which is of the same conductivity type and the emitter of which is connected to the bases of the first and second transistors, whilst its base is connected to the input terminal of the current amplifier. In the circuit shown the collector of this third transistor is connected to a point of constant potential.

This structure of the current amplifier ensures that the deviation from the desired current amplification due to the base currents of the first and second transistors is very

small, for the influence of these base currents on the current flowing through the input current circuit is reduced owing to the current amplification factor between the base and the emitter of the third transistor. If this current amplification factor is large, the base current for the third transistor derived from the input terminal will be very small with respect to this input current, so that the current amplification is determined, with a high degree of accuracy, by the ratio between the emitter areas of the first and second transistors.

The required supply voltage is about twice the base emitter voltage of each of the transistors, because there is connected between the input terminal and the emitters of the first and second transistors the series combination of two base emitter paths, namely the base emitter path of the third transistor and the parallel-connected base emitter paths of the first and second transistors.

It is an object of the present invention to provide a circuit arrangement of the type described at the beginning of this specification which also enables an accurately determined current amplification to be realized but which may be operated with a supply voltage which is considerably smaller than that used in the known circuit arrangement.

The circuit arrangement according to the invention is characterized in that the third transistor is of the complementary conductivity type and at its base electrode receives a control signal via the main current path of a fourth transistor, the base electrode of which is connected to the input current circuit.

If, for example, the base emitter paths of the first and the second transistors are connected in parallel, there is obtained a current amplifier the amplification of which is determined by the ratio between the emitter areas of these transistors. The influence of the base currents of these transistors on the input current is small, because the influence of these base currents is reduced not only owing to the current amplification factor of the third transistor but also owing to the current amplification factor of the fourth transistor. The

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circuit arrangement according to the invention, however, may be operated with a smaller supply voltage than the known circuit arrangements, namely with the sum of one base emitter voltage and one collector emitter knee voltage, i.e. about 0.9 volts, which is less than the terminal voltage of a single voltage cell.

It should be noted that a current amplifier adapted to be operated with an even smaller supply voltage is known. However, in this current amplifier the required base currents for the first and second transistors are obtained by short-circuiting the collector base path of the first transistor, with the result that the required base currents of the transistors without attenuation disturb the desired ratio between the input and output currents. When transistors having large current amplification factors are used, this disturbance of the desired current ratio will be comparatively small. If, however, lateral *pnp* transistors are used, the disturbance becomes considerable, because these transistors have small current amplification factors, particularly in the base of small currents.

If lateral *pnp* transistors are used, then in addition to the advantage of a small supply voltage, a further advantage of the circuit arrangement according to the invention compared with the known circuit mentioned at the beginning of this specification occurs. As has already been mentioned, these lateral *pnp* transistors have small current amplification factors, so that in a circuit arrangement in which all the transistors are of this *pnp* type, the deviation from the desired ratio between the input and output currents due to the base currents will be considerable. In the circuit arrangement according to the invention, however, in this case the third transistor can be of the vertical *nnp* type and hence has a large current amplification factor, so that the deviation from the desired current amplification may be considerably smaller than in the known circuit arrangement.

The circuit arrangement according to the invention has the further advantage that very large input signals can be handled by including a current source in the collector lead of the fourth transistor.

The circuit arrangement according to the invention is particularly useful in realizing a current stabilizer. In such a stabilizer two intercoupled current amplifiers are used enabling at least one current to be obtained the value of which is accurately determined and is substantially independent of supply voltage variations. Proper use of the circuit arrangement according to the invention enables an accurate current stabilizer to be realized which is capable of controlling a large number of current sources, and requires only a small supply voltage and in which the starting

problems inherent in these current stabilizers are largely eliminated.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying diagrammatic drawings, in which:

Figure 1 is a diagram of the known current amplification circuit,

Figures 2, 3 and 4 are diagrams of three embodiments of the current amplifier circuit according to the invention, and

Figure 5 shows a current stabilizer circuit in which the current amplifier circuit according to the invention is appropriately used.

Figure 1 shows the known current amplifier circuit which includes two *nnp* transistors T_1 and T_2 the base emitter paths of which are connected in parallel. The collector of the transistor T_1 is connected to an input terminal A to which an input current is supplied. The collector of the transistor T_2 is connected to an output terminal from which the output current is derived. For driving these two transistors T_1 and T_2 , a transistor T_3 of the *nnp* type is provided the emitter of which is connected to the bases of the transistors T_1 and T_2 , the base of which is connected to the input terminal A and the collector of which is connected to a point of constant potential, for example, to the positive terminal $+V_B$ of the voltage supply source.

The current amplification of the circuit, i.e. the ratio between the input and output currents, is substantially determined by the ratio between the emitter areas of the transistors T_1 and T_2 . Assuming, for example, the emitter areas of these transistors to be equal, their emitter currents always are accurately equal. If the current amplification factors of the transistors T_1 and T_2 are equal, the collector currents of the transistors T_1 and T_2 also will be equal, for example will both be I . The output current at the terminal B is equal to the collector current of the transistor T_2 , so that the equality of the input and output currents is disturbed only by the base current I_b of the transistor T_3 , i.e. the input current $I_1 = I + I_b$. Assuming the three transistors to have the same current amplification factor β_n between base and collector, the base current of the transistor T_3 will be:

$$I_b = 2I / \beta_n (\beta_n + 1) \quad (1)$$

This expression clearly shows that when transistors having large current amplification factors are used the deviation due to this base current is very small, so that the desired current amplification is achieved with a high degree of accuracy. The required minimum supply voltage for the current amplification shown is given by the voltage required between the input terminal A and the emitters of the transistors T_1 and T_2 . As the Figure

shows, these points are connected by the series combination of two base emitter paths, namely the base emitter path of the transistor T_3 and the parallel connection of the base emitter paths of the transistors T_1 and T_2 , which means that a voltage is required which at least is twice the base emitter voltage of a conducting transistor. When silicon transistors are used this would mean that the supply voltage should be at least about 1.2 volts.

Figure 2 shows a first embodiment of the current amplifier according to the invention. The circuit again includes two transistors T_1 and T_2 of the *npn* type the base emitter paths of which are connected in parallel and the collectors of which are connected to the input terminal A and to the output terminal B respectively. However, for driving these two transistors the circuit includes two transistors, a transistor T_3 of the *npn* type and a transistor T_4 of the *npn* type. The collector of the transistor T_3 is connected to the bases of the transistors T_1 and T_2 , and its emitter is connected to a point of constant potential, for example to the positive terminal $+V_B$ of the supply source. Its base is connected to the collector of the transistor T_4 , the base of which is connected to the input terminal and the emitter of which is connected, for example, to the emitters of the transistors T_1 and T_2 .

Again it will readily be seen that the current amplification is determined by the ratio between the emitter areas of the transistors T_1 and T_2 and that a deviation from the desired current amplification is produced by the base current I_b of the transistor T_4 . Again assuming, for example, that the emitter areas of the transistors T_1 and T_2 are equal, their collector currents will be equal, for example, will be I_c , and the input current will be $I_i = I_c + I_b$, in complete agreement with Figure 1. However, I_b here is:

$$I_b = 2I / \beta_p \cdot \beta_n^2 \quad (2)$$

where β_n is the current amplification factor of the *npn* transistors and β_p is the current amplification factor of the *pnp* transistor T_4 . A comparison of the expression (2) with the expression (1) shows that the deviation due to the base current I_b will be smaller by approximately a factor of β_p .

A very important advantage of the circuit shown in Figure 2 will become apparent when the required supply voltage is considered. The voltage required between the input terminal A and the emitters of the transistors is only about 0.6 volts (silicon transistors), i.e. the base emitter voltage required for the transistor T_4 . The voltage between the emitter of the transistor T_3 and the emitters of the transistors T_1 and T_2 need not exceed 0.9 volts, because the said points are connected

to one another by one base emitter path and one collector emitter path only. As a result, the entire circuit may be operated with a supply voltage of about 0.9 volts, as compared to 1.2 volts in the known circuit. Obviously this is of high importance in battery-fed devices in which a minimum of cells and preferably a single cell are desired.

Figure 3 shows a second embodiment the circuit of which entirely corresponds to that shown in Figure 2, with the difference that the transistors T_1 , T_2 and T_4 here are the *pnp* and the transistor T_3 is of the *npn* Type. Compared with the known circuit shown in Figure 1, but modified to use *pnp* transistors, this circuit first has the advantage that the required supply voltage is smaller. In addition, however, the deviation from the desired current amplification used in this circuit is greatly reduced in comparison with the known circuit. When the circuit shown in Figure 1 is made up of *pnp* transistors, the expression for the base current I_b of the transistor T_3 corresponds to that in equation (1); however, the current amplification factor β_n of the *npn* transistors must be replaced by the current amplification factor β_p of the *pnp* transistors:

$$I_b = 2I / \beta_p (\beta_p + 1) \quad (3)$$

In an integrated circuit *pnp* transistors generally take the form of lateral transistors and hence have a comparatively low current amplification factor β_p . As a result the base current I_b is comparatively large and hence the deviation from the desired current amplification due to this base current will also be comparatively large.

The base current I_b of the transistor T_4 in the circuit shown in Figure 3 can be expressed by

$$I_b = \frac{2I}{\beta_n \beta_p^2} = 2I / \beta_n \beta_p^2 \quad (4)$$

from which it directly follows that this base current remains very small owing to the factor β_n , the current amplification factor of the vertical *npn* transistor T_3 , which may be great. Thus, in addition to the advantage of a smaller supply voltage the circuit shown in Figure 3 when compared with the known circuit provided with lateral *npn* transistors also has the advantage that the deviation from the desired current amplification is greatly reduced. Obviously this property may be further improved by replacing the *pnp* transistor by an equivalent *pnp* transistor, that is to say by a multi-transistor circuit which is functionally equivalent to a *pnp* transistor but has a considerably higher current gain.

Figure 4 shows a third embodiment which largely corresponds to that shown in Figure

3 but in which provisions have been made to improve the frequency behaviour. Because the transistors T_3 and T_4 of Figure 3 carry a small direct current, their cut-off frequency will be low. A diode or a transistor connected as a diode D may be connected between the emitters and the bases of the transistors T_1 and T_2 , which ensures that the transistor T_3 carries a larger current and hence its cut-off frequency is increased. To increase the quiescent current of the transistor T_4 also, a current source J may be included in its collector lead. Alternatively, the base-emitter path of the transistor T_3 may be shunted by a diode or a transistor connected as a diode.

However, with large input signals the use of a current source J has a particular advantage. With a large drive signal the currents flowing through the transistors T_1 to T_4 will become very small during the negative peak of the signal at the input. This means, however, that the impedances of these transistors become very high, so that the input impedance becomes very high. As a result the stray capacitances of the transistor T_1 will play an important role and cause an undesirable phase shift of the signal. This is avoided by the use of the current source J, because the transistor T_4 then will remain highly conducting and the input impedance will remain low, so that no undesirable phase shift of the signal occurs.

Figure 5 shows an example of the manner in which the current amplification circuit according to the invention may be used to particularly great advantage to realize a current stabilizer circuit. The intention of such a current stabilizer is to supply currents which may serve as quiescent currents for the elements of an integrated circuit, which currents are exactly defined and are highly independent of the supply voltage. The current stabilizer shown in Figure 5 comprises a current amplification circuit S_1 having an input terminal A and an output terminal B, which circuit largely corresponds to that shown in Figure 4. However, in this circuit the emitter of the transistor T_2 is not directly connected to the emitter of the transistor T_1 but via a resistor R, whilst the transistor T_2 has a greater emitter area than the transistor T_1 , which for clarity is shown by the parallel connection of three transistors. To improve the frequency behaviour of the circuit transistors T_1 and T_2 connected as diodes are included, which corresponds to the diode and the current source of Figure 4, so that the transistors T_3 and T_4 carry larger currents.

The current stabilizer further includes a second current amplifier circuit S_2 which comprises transistor T_5 and T_6 which have equal emitter areas and the base emitter paths of which are connected in parallel, whilst the transistor T_7 is connected as a diode. An input terminal A' of this second

current amplifier S_2 is connected to the output terminal B of the first current amplifier S_1 , and an output terminal B' of this second current amplifier is connected to the input terminal A of the first current amplifier S_1 .

Of necessity the input and output currents of the current amplifier S_2 are equal and hence so are the input and output currents of the current amplifier S_1 . Neglecting the base current of the transistor T_4 , the collector currents, and hence to a good approximation the emitter currents also, of the transistors T_1 and T_2 will be equal. As a result, the magnitudes of these currents are completely determined, because the base emitter voltage of the transistor T_1 associated with this emitter current must be equal to the sum of the base emitter voltage of the transistor T_2 associated with this current and the voltage across the resistors R. Consequently, the magnitudes of the currents are completely determined by the resistance value of the resistor R and the ratio between the emitter areas of the transistors T_1 and T_2 , and are substantially independent of the supply voltage.

This current stabilizer enables a plurality of current sources to be controlled in that, for example, the base emitter paths of transistors T_{01} to T_{04} are connected in parallel with the base emitter path of the transistor T_1 , so that their collector currents and hence the currents at terminals I_{01} to I_{04} are completely determined by the current of the current stabilizer.

A first advantage of the current stabilizer shown consists in that a very small supply voltage may be used. Even an overall supply voltage of about 0.9 volts is sufficient to operate the circuit. Furthermore the accuracy of the circuit is very high, because the current deviation due to the base current of the transistor T_4 is small. The current stabilizer is capable of controlling a large number of current sources, because the currents required for these current sources, in the embodiment shown the base currents of the transistors T_{01} to T_{04} , can readily be supplied by the transistor T_8 . A further advantage of the circuit is that the starting difficulties which occur in the known current stabilizers of this type are substantially eliminated. Current stabilizers of this type in principle have a stable state in which the currents are zero, so that special provisions have to be made to bring the current stabilizer out of this stable state into the desired stable state in which the currents differ from zero. It has been found that in a current stabilizer provided with a current amplifier according to the invention such special provisions can be dispensed with, because when the currents are zero the loop amplification is such as to automatically bring the current stabilizer in the desired stable state.

It will be clear that the current stabilizer

shown in Figure 5 may be modified in many respects. For example, the current amplifier S_2 may be replaced by another known current amplifier. It may also be a current amplifier according to the invention. The resistor need not be included in the current amplifier S_1 , but may alternatively be included in the current amplifier S_2 , in which case the emitter area of the associated transistor must be correspondingly changed. The input and output currents of the current amplifier circuit need not be equal. Altogether many modifications are possible which, however, have the common feature that at least one of the current amplifiers is provided with a control of the transistors having parallel connected base emitter paths as described with reference to Figures 2 to 5 and defined in the appendant Claims.

20 WHAT WE CLAIM IS:—

1. Circuit arrangement having a constant current amplification, comprising an input current circuit which includes the main current path of a first transistor of one conductivity type and an output current circuit which includes the main current path of a second transistor of the said one conductivity type, the base electrodes of the first and second transistors being interconnected, whilst the base electrode currents of these transistors are supplied via the main current path of a third transistor, characterized in that the third transistor is of the complementary conductivity type and at its base electrode receives a control signal via the main current path of a fourth transistor of the one conductivity type the base electrode of which is connected to the input current circuit.

2. Circuit arrangement as claimed in claim 1, further including a diode, or a transistor connected as a diode, forming a current source for the main current path of the fourth transistor.

3. Circuit arrangement as claimed in claim 1 or claim 2, characterized in that in order

to obtain a current stabilizer circuit there is connected in series with the input current circuit of this, first, current amplifier circuit the output current circuit of a second current amplifier circuit, and there is connected in series with the output current circuit of the first current amplifier the input current circuit of the said second current amplifier circuit, which second current amplifier circuit includes a fifth and a sixth transistor of the complementary conductivity type the base electrodes of which are interconnected, the main current path of the fifth transistor being connected in the input current circuit of the second current amplifier and the main current path of the sixth transistor being connected in the output circuit of this second current amplifier circuit, whilst one of the current amplifier circuits is arranged to supply two currents in a fixed ratio to one another to the other current amplifier circuit, which latter circuit includes a resistor which is connected in the respective current amplifier circuit in series with the main current path of one of the transistors.

4. Circuit arrangement as claimed in claim 3, characterized in that the transistors of the type are lateral *pnp* transistors and the transistors of the complementary type are vertical *nnp* transistors, the fifth transistor being connected as a diode.

5. Circuit arrangement, having constant current amplification, substantially as hereinbefore defined with reference to Figure 2, 3 or 4 of the accompanying drawings.

6. Current stabilizer circuit including a circuit arrangement as claimed in any previous claim and substantially as hereinbefore described with reference to Figure 5 of the accompanying drawings.

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2. Circuit arrangement as claimed in claim 1, further including a diode, or a transistor connected as a diode, forming a current source for the main current path of the fourth transistor.

3. Circuit arrangement as claimed in claim 1 or claim 2, characterized in that in order

to obtain a current stabilizer circuit there is connected in series with the input current circuit of this, first, current amplifier circuit the output current circuit of a second current amplifier circuit, and there is connected in series with the output current circuit of the first current amplifier the input current circuit of the said second current amplifier circuit, which second current amplifier circuit includes a fifth and a sixth transistor of the complementary conductivity type the base electrodes of which are interconnected, the main current path of the fifth transistor being connected in the input current circuit of the second current amplifier and the main current path of the sixth transistor being connected in the output circuit of this second current amplifier circuit, whilst one of the current amplifier circuits is arranged to supply two currents in a fixed ratio to one another to the other current amplifier circuit, which latter circuit includes a resistor which is connected in the respective current amplifier circuit in series with the main current path of one of the transistors.

4. Circuit arrangement as claimed in claim 3, characterized in that the transistors of the type are lateral *pnp* transistors and the transistors of the complementary type are vertical *nnp* transistors, the fifth transistor being connected as a diode.

5. Circuit arrangement, having constant current amplification, substantially as hereinbefore defined with reference to Figure 2, 3 or 4 of the accompanying drawings.

6. Current stabilizer circuit including a circuit arrangement as claimed in any previous claim and substantially as hereinbefore described with reference to Figure 5 of the accompanying drawings.

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