

PATENT SPECIFICATION

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(54) HALL-EFFECT INTEGRATED CIRCUIT

(71) We, MOTOROLA, INC., a corporation organised and existing under the laws of the State of Delaware, United States of America, of 1303 East Algonquin Road, Schaumburg, Illinois 60196, United States of America, 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 present invention relates to a Hall-effect integrated circuit which compensates for changes in Hall-effect current due to temperature variations.

An integrated circuit in which the Hall-Effect device and the sensing circuit can be incorporated on a single monolithic chip includes a Hall-effect generator responsive to a magnetic flux change for generating a Hall-effect voltage. A differential amplifier and current mirror circuit are coupled to the Hall-effect device in order to vary or track the threshold voltage of the differential amplifier circuit in accordance with the output voltage from the Hall-effect device irrespective of current changes in the Hall-effect device due to temperature variations.

A Hall-Effect device is a block of semiconductor material which acts as a transducer to convert magnetic flux density into an electrical potential. When a current is passed from one end of the semiconductor material to the other, hole-electron pairs are formed inside the semiconductor material. A magnetic field perpendicular to the flow of the current will cause the holes and electrons to separate producing a voltage potential which can be measured between the opposite sides of the semiconductor material. This voltage is proportional to the flux density of the magnetic field and the magnitude of the current flowing through the Hall-Effect device and is mathematically represented by:

$V_H = K I_H \beta$, where K = device constant; I_H = Hall current; and β = magnetic flux density.

Since the Hall-Effect device is made of semiconductor material, a constant voltage applied across the device will produce a current through the Hall-Effect device which varies inversely with temperature. As a result the accuracy of the Hall-Effect transducer is impaired.

In the past one solution attempted to avoid this problem by employing a constant current generator. However, certain problems arose with this approach. Firstly, an ideal constant current source is difficult to build with integrated circuit devices since they contain nonlinear monolithic resistors. A further problem is that there is a temperature dependence associated with the epitaxial silicon Hall resistance despite the use of constant current regulation. A detailed discussion of this latter phenomenon is described in the article entitled "Modular Hall Masterslice Transducer" by R.J. Braun appearing in IBM Journal Research and Development, July, 1975.

The present invention takes a different approach for Hall-Effect devices in applications where a threshold voltage is to be detected. No constant current sources are required, but rather a differential sensing device is coupled to the Hall-Effect device and it samples the current flowing through the device and adjusts the threshold voltage of the sensing circuit to compensate for any changes in Hall-Effect current due to temperature variations. Thus, the Hall-Effect device and the sensing circuit are referenced together so that both the voltage produced by the Hall-Effect device and the voltage threshold of the comparator or sensing circuit are both a function of current flowing through the Hall-Effect device.

Thus, according to the present invention

there is provided a Hall-Effect circuit comprising a Hall-Effect semiconductor device responsive to a magnetic flux for providing a Hall-Effect output signal in response to the magnetic flux and having a Hall-Effect current flowing therethrough sensitive to temperature variations, sensing means coupled to said Hall-Effect device, said sensing means having an operating current and a threshold voltage responsive to said operating current, said sensing means being effective to generate an output voltage at a time when said Hall-Effect output signal reaches said threshold voltage, said sensing means comprising a differential amplifier circuit having a pair of differentially coupled transistors, and means coupled to said Hall-Effect device and to said sensing means for maintaining said operating current at a value which has a predetermined relationship to said Hall-Effect current during temperature variations for causing said threshold voltage to track with said Hall-Effect current such that the generating of the output voltage effected by said sensing means is substantially independent of temperature variation.

The invention will now be described by way of example only with particular reference to the accompanying drawing wherein

Figure 1 illustrates an electrical schematic of the present invention;

Figure 2 is a series of curves illustrating the Hall-Effect voltage and the threshold voltage of the comparator plotted against the Hall-Effect current; and

Figure 3 illustrates the present invention being incorporated on a single monolithic semiconductor chip.

Now referring to Figure 1, it illustrates a Hall-Effect generator device 10 coupled to a differential sensing or comparator circuit 12. A conventional current mirror circuit 14 comprising a semiconductor diode 16 in one leg and an NPN transistor 18 in the other leg is coupled between the Hall generator 10 and the comparator or sensing circuit 12. The sensing circuit 12 comprises a pair of differentially connected transistors 20 and 22 coupled to supply voltage V_{CC} by line 24 and load resistor R_L , respectively. A resistor R_1 is commonly connected between the emitter terminals of transistors 20 and 22. Variable resistor R_1 is external to the Hall-Effect integrated circuit such that its resistance value is not subject to temperature variations and such that its resistance value can be adjusted to select the desired threshold voltage. Diode 16 is coupled to the Hall generator by line 26 and line 28 couples the collector terminal of transistor 18 to the emitter terminal of transistor 20.

In the preferred embodiment, the plot of Figure 2 illustrates that at flux densities of less than 300 gauss the threshold voltage

V_{TH} of the sensing circuit 12 will not be reached by the Hall voltage V_H while flux densities of greater than 400 gauss will generate a Hall voltage V_H greater than the threshold voltage V_{TH} .

Figure 3 illustrates a body of semiconductor material 30 having a Hall-Effect device 32 and an integrated circuit 34 formed in the body. In actual implementation Hall-Effect device 32 would correspond to the device 10 of Figure 1 and integrated circuit 34 would correspond to the remainder of the circuitry with the exception of external resistor R_1 .

The current mirror circuit 14 causes the value of current I_H flowing in line 28 to equal the Hall-Effect current I_H generated in line 26 connected to the Hall-Effect device 10. Thus despite temperature variations the current in lines 26 and 28 will remain essentially the same.

At the threshold point of the comparator, identical collector and emitter currents are flowing in both of the differential transistors 20 and 22, i.e., $I_H/2$. Thus, the voltage across resistor R_1 equals $I_H R_1/2$. As a result, at the threshold point of the comparator, the base of transistor 22 is more positive than the base of transistor 20 by the voltage offset or threshold voltage $V_{TH} = 1/2 I_H R_1 = K_2 I_H$.

As previously set forth, the Hall voltage V_H existing across terminals 36 and 38 is represented by: $V_H = K_1 I_H \beta$. Accordingly, the point at which the sensing circuit 12 generates an output signal V_O is substantially independent of Hall current I_H since K_1 and K_2 are constants. Temperature induced current variations in the Hall device 10 do not affect the accuracy of a Hall sensing device at erroneous Hall voltage levels as the threshold voltage of the sensing circuit 12 tracks with Hall current changes.

WHAT WE CLAIM IS:-

1. A Hall-Effect circuit comprising a Hall-Effect semiconductor device responsive to a magnetic flux for providing a Hall-Effect output signal in response to the magnetic flux and having a Hall-Effect current flowing there-through sensitive to temperature variations, sensing means coupled to said Hall-Effect device, said sensing means having an operating current and a threshold voltage responsive to said operating current, said sensing means being effective to generate an output voltage at a time when said Hall-Effect output signal reaches said threshold voltage, said sensing means comprising a differential amplifier circuit having a pair of differentially coupled transistors, and means coupled to said Hall-Effect device and to said sensing means for maintaining said operating current at a value which has a predetermined relationship to said Hall-Effect current during temperature variations for causing said



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The current mirror circuit 14 causes the value of current I_H flowing in line 28 to equal the Hall-Effect current I_H generated in line 26 connected to the Hall-Effect device 10. Thus despite temperature variations the current in lines 26 and 28 will remain essentially the same.

At the threshold point of the comparator, identical collector and emitter currents are flowing in both of the differential transistors 20 and 22, i.e., $I_H/2$. Thus, the voltage across resistor R_1 equals $I_H R_1/2$. As a result, at the threshold point of the comparator, the base of transistor 22 is more positive than the base of transistor 20 by the voltage offset or threshold voltage $V_{TH} = 1/2 I_H R_1 = K_2 I_H$.

As previously set forth, the Hall voltage V_H existing across terminals 36 and 38 is represented by: $V_H = K_1 I_H \beta$. Accordingly, the point at which the sensing circuit 12 generates an output signal V_O is substantially independent of Hall current I_H since K_1 and K_2 are constants. Temperature induced current variations in the Hall device 10 do not affect the accuracy of a Hall sensing device at erroneous Hall voltage levels as the threshold voltage of the sensing circuit 12 tracks with Hall current changes.

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1. A Hall-Effect circuit comprising a Hall-Effect semiconductor device responsive to a magnetic flux for providing a Hall-Effect output signal in response to the magnetic flux and having a Hall-Effect current flowing there-through sensitive to temperature variations, sensing means coupled to said Hall-Effect device, said sensing means having an operating current and a threshold voltage responsive to said operating current, said sensing means being effective to generate an output voltage at a time when said Hall-Effect output signal reaches said threshold voltage, said sensing means comprising a differential amplifier circuit having a pair of differentially coupled transistors, and means coupled to said Hall-Effect device and to said sensing means for maintaining said operating current at a value which has a predetermined relationship to said Hall-Effect current during temperature variations for causing said



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threshold voltage to track with said Hall-Effect current such that the generating of the output voltage effected by said sensing means is substantially independent of temperature variation.

5 3. A Hall-Effect circuit as claimed in Claim 2 wherein said means coupled to said Hall-Effect device and to said sensing means comprises a first terminal and a second
10 terminal, said first terminal being coupled to said Hall-Effect device for conducting said Hall-Effect current, and said second terminal being coupled to said sensing means for providing said operating current.

15 4. A Hall-Effect circuit as claimed in Claim 3 wherein said means coupled to said Hall-Effect device and to said sensing means comprises a current mirror circuit for maintaining said operating current at a value
20 which has a predetermined relationship to said Hall-Effect current.

5. A Hall-Effect circuit as claimed in Claim 1 wherein said Hall-Effect current flowing through said Hall-Effect semiconductor device is a d.c. current.

25 6. A Hall-Effect circuit substantially as hereinbefore described with reference to the accompanying drawings.

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