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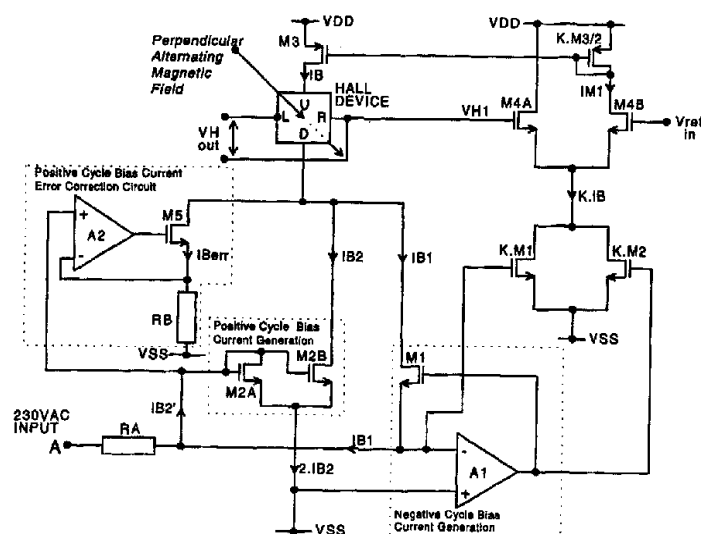
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(54) Title: ELECTRICITY MEASUREMENT APPARATUS



(57) Abstract

An electricity meter includes a sensor supplied with a rectified A.C. supply signal, the sensor detecting the strength of magnetic field induced by current flow along a conductor and providing an output signal following a sine-squared relation with alternating positive and negative sign in each half cycle, the output signal being filtered to remove a component due to D.C. offset error.

ELECTRICITY MEASUREMENT APPARATUS

The present invention relates to an electricity measurement apparatus and a method of electricity measurement, in particular for current measurement, power measurement and Watthour metering.

When current flows through a conductor, a rotational magnetic field is set up. The magnitude of this magnetic field is proportional to the density of current flowing:

$$B \propto I/A \quad (\text{Equation 1})$$

where I is the total current, and A is the cross sectional area of the conductor. This value I/A is the current density J.

It is known to use sensors, such as Hall effect sensors, to measure current flow through a conductor by detecting the magnetic field. For example, using a Hall effect sensor, the sensor output signal has a voltage, V_H , which is proportional to the magnetic field strength B at the sensor, and a bias current I_B flowing through the sensor as follows:

$$V_H = S \times B \times I_B \quad (\text{Equation 2}).$$

The proportionality coefficient S is the sensitivity of the sensor. By keeping constant the current through the Hall sensor, a linear relationship is achieved between the detected

magnetic field and output voltage.

If such a sensor is placed near a conductor, the two equations (1) and (2) above can be combined allowing current flow to be determined:

$$V_H \propto J \quad (\text{Equation 3}).$$

Hall sensors produce Direct Current (D.C.) offset errors, which are independent of the direction (positive or negative) with which the bias current I_B is applied to the sensor. Conventionally, the bias current I_B is selected to be proportional to the electricity mains supply voltage. The current I_B and detected magnetic field B are both Alternating Current (A.C.) signals which vary according to a sine relation. Accordingly, the output voltage V_H follows a sine squared relation where D.C. offsets are components of the resultant V_H signal.

Other D.C. offsets can also occur due to the electronic circuits associated with the subsequent processing operations.

The effects of D.C. offsets are minimised conventionally by using large Hall sensors, in particular so called "external" sensors not integrated with other processing circuitry on an integrated circuit such as a silicon chip. The conventional principle applied is that the larger the Hall sensor is, the larger is the Hall voltage which it provides relative to its D.C. offset error.

The present invention is defined in the claims to which reference should now be made.

Preferred features are laid out in the subclaims.

The present invention preferably provides an electrical measurement apparatus comprising supply means operative to supply a rectified A.C. supply signal to a sensor, the sensor being operative to detect magnetic field strength due to A.C. current flow along a conductor and to provide an output signal dependent on detected field strength and the rectified A.C. supply signal, the output signal following a sine-squared relation with alternating positive and negative sign in each half cycle, and filtering means operative to remove a component due to a D.C. offset error from the output signal. The rectified A.C. signal is preferably a rectified A.C. bias current signal. The filtering means preferably comprises a capacitor. The A.C. mains signal is the alternating voltage signal of an electrical supply network to which the conductor is connected.

It will be seen that preferred embodiments of the invention have the advantage that components due to D.C. offset errors are cancelled. This is done in a simple and automatic manner. In consequence, further advantages arise. In particular, sensors can be made sufficiently small that multiple sensors can be integrated on a single silicon chip.

Preferably, the sensor is a Hall sensor and the supply signal to the sensor is a current signal. The supply signal is preferably proportional to the electricity mains supply voltage. The output signal from a sensor is preferably a voltage signal. The A.C. current flow along the conductor is preferably an electricity mains supply current.

The present invention also provides a method of measuring electricity flow along a conductor

including the steps of supplying a rectified A.C. supply signal to a sensor, the sensor detecting magnetic field strength due to A.C. current flow along a conductor and providing an output signal dependent on detected field strength and the rectified A.C. supply signal, the output signal following a sine-squared relation with alternating positive and negative sign in each half cycle, and filtering to remove a component due to D.C. offset error from the output signal.

A preferred embodiment of the present invention will now be described by way of example only with reference to the drawings in which:-

Figure 1 is a circuit diagram for an embodiment of the invention; and

Figure 2 shows wave forms for supply current and output Hall voltage in a circuit according to the present invention; and

Figure 3 shows corresponding wave forms to Figure 2 for a typical known circuit (prior art) for comparison.

As described this invention relates to apparatus and a method for eliminating D.C. voltage offset errors in a multiplying circuit used in an energy measurement circuit. The preferred method of energy measurement is based on the alternating current flow to be measured producing an alternating magnetic field B , that field being detected using an electronic circuit containing an Hall effect device. The A.C. voltage to be measured is converted to a Hall bias current I_B and applied across the Hall effect device. The resulting Hall voltage V_H is

proportional to the instantaneous power being conducted.

Figure 1 shows a schematic of a circuit capable of producing an instantaneous Hall bias current, I_B , of amplitude proportional to the instantaneous A.C. voltage applied to the input port A. The circuit is arranged to produce an instantaneous Hall bias current which is in phase with the applied A.C. voltage during the positive half cycle of the A.C. voltage, and is 180 degrees out of phase with the applied A.C. voltage during the negative half cycle of the applied A.C. voltage. These waveforms are shown on figure 2.

When an alternating magnetic field is applied to the Hall effect device in a plane which perpendicular to the direction of Hall bias current flow, an alternating $\sin^2\theta$ Hall voltage waveform V_H is generated by the Hall effect device. This waveform is shown on figure 2 and is a piecewise waveform following:

$\sin^2\theta$ for positive half cycles

$-\sin^2\theta$ for negative half cycles

where θ is phase (being representative of time). This waveform can be expressed mathematically as:

$$\begin{aligned} V_H &= A \sin^2\theta && \text{for } \theta \text{ in the range } 0 \text{ to } \pi \\ &= -A \sin^2\theta && \text{for } \theta \text{ in the range } \pi \text{ to } 2\pi \end{aligned}$$

More strictly, this waveform can be expressed as:

$$V_H = \begin{matrix} A \sin^2 \phi & \forall \phi \in [0, \pi) \\ -A \sin^2 \phi & \forall \phi \in [\pi, 2\pi) \end{matrix}$$

where A is a constant and ϕ is representative of time following the equation $\phi = 2\pi ft$, with f being a signal frequency in Hertz and t being time in seconds.

Where the symbols have the following meanings:

$\forall$ means "for all values of".

$\in$ means "is in the range".

'[' means from and including the value stated immediately after the bracket. (The mathematical term is a "closed limit").

')' means up to but not including the value stated immediately before the bracket. (The mathematical term is an "open limit").

Therefore, the expression " $\forall \phi \in [0, \pi)$ " signifies "for all values of ϕ in the interval from and including 0 up to but not including π ".

The instantaneous amplitude of this alternating $\sin^2 \phi$ voltage waveform is proportional to the multiplication of the instantaneous amplitude of the alternating magnetic field B and the Hall bias current IB. Since the Hall bias current IB is proportional to the A.C. voltage applied to the input port A and the alternating magnetic field B is proportional to the alternating current flow through the conductor, the amplitude of the alternating $\sin^2 \phi$ Hall voltage waveform.

VH, is proportional to the instantaneous power flow.

The production of the alternating $\sin^2\theta$ Hall voltage waveform VH allows simple elimination of any unwanted D.C. voltages in the circuit by filtering out D.C. voltages using a D.C. blocking capacitor. Unwanted D.C. voltages can occur due to Hall effect device D.C. offsets and amplifier D.C. offsets. D.C. voltages on the Hall voltage VH can also be caused by external D.C. magnetic fields. All of these D.C. voltages are simply removed by using a simple D.C. blocking capacitor.

The circuit shown in figure 1 also centres the alternating $\sin^2\theta$ Hall voltage waveform, VH, on Vref allowing the Hall effect device to be operated in its linear region.

In the circuit VDD is the positive circuit supply voltage typically 5VoltsDC, VSS is the negative circuit supply voltage typically 0VoltsDC and Vref is typically the voltage midpoint between these, typically 2.5VoltsDC.

Detailed description of circuit

Referring again to figure 1, the approach is to generate a Hall bias current IB proportional to the applied A.C. voltage in two different ways for each of the two half cycles of the A.C. voltage applied to input A.

The A.C. voltage is applied to the input A of resistor RA.

During negative half cycles of the A.C. voltage, applied to input A, the A.C. voltage is converted to Hall bias current IB_1 by Resistor RA, Transistor M1 and Amplifier A1 in a conventional fashion.

During the positive half cycle, bias current is created with the same polarity as during the negative half cycle. This is achieved by Resistor RA, and Transistors M2A and M2B. A bias current IB_2 is generated and flows through transistor M2B which matches the current flowing through RA and transistor M2A. This matching is achieved since transistor M2A and M2B are arranged in what is commonly known as a "current mirror". There is a small error in this second half cycle of the A.C. voltage to Hall bias current conversion since transistor M2A fails to operate below around 2VoltsDC. This is compensated for by amplifier A2, transistor M5 and resistor RB which create the bias current IB_{err} during this inoperative region. The resistance value of resistor RB is essentially the same as the resistance value of resistor RA.

As thus far described, the circuit has created the desired rectified Hall bias current IB . The second half of the circuit using transistors K.M1, K.M2, M4A, M4B, K.M3/2 and M3 is included to centre the Hall voltage V_H on V_{ref} . The Hall voltage is maintained such that the midpoint of its amplitude takes the midpoint value between maximum possible output voltage V_{DD} and minimum possible output voltage V_{SS} of the Hall device. For example the Hall voltage V_H is centred on V_{ref} where V_{ref} is 2.5V D.C., where the maximum possible Hall voltage output is 5V and the minimum is 0V. The Hall voltage thus varies around its midpoint output where the response of the Hall device is most linear.

The Hall voltage is centred on V_{ref} by careful control of the current into the Hall device

which is controlled by transistor M3. The Hall bias current I_B flows through M3 from the supply VDD, through the Hall device and becomes either I_{B1} , I_{B2} or I_{Berr} . The centre voltage of the Hall device can however be varied by changing the impedance of transistor M3. The input to control this voltage V_{ref} is at M4B. Transistors M4A and M4B are arranged as a Long Tailed Pair ie. with their emitters connected to a current source. The current source is generated by transistors K.M1 and K.M2. This current source is proportional to the Hall bias currents I_{B1} and I_{B2} since the same control signals are input to K.M1 and K.M2 as M1 and M2A. Transistors K.M3/2 and M3 are arranged as a "current mirror", with current I_{M1} flowing through K.M3/2 being mirrored through M3.

Since these components are interconnected with a feedback loop through the Hall device back to M4A, a description of circuit operation is best given by examples of what happens under certain conditions as described below.

If the voltage V_{H1} at the gate of M4A is equal to V_{ref} on the gate of M4B then equal currents will flow through M4A and M4B. The currents through M4A and M4B are controlled by K.M1 and K.M2 and are equal to $K.I_B$ at all times as described earlier. Hence $K.I_B/2$ flows through M4A and M4B respectively. It follows that $K.I_B/2$ flows through K.M3/2. Since K.M3/2 and M3 are arranged as a "current mirror", the current $K.I_B/2$ is mirrored across to M3 with a gain in magnitude of 2/K. Therefore current I_B flows in M3, exactly as needed to keep equilibrium.

If the voltage V_{H1} at the gate of M4A is lower than V_{ref} , less current will flow through M4A than M4B. Since the total current through M4A and M4B must be $K.I_B$, transistor

$K.M3/2$ will conduct more than $K.IB/2$. Therefore M3 will try to conduct more than IB. This leads to an increase in voltage on the R contact of the Hall device until $VH1$ equals $Vref$.

If the voltage $VH1$ at the gate of M4A is higher than $Vref$, more current will flow through M4A than M4B. Since the total current through M4A and M4B must be $K.IB$, transistor $K.M3/2$ will conduct less than $K.IB/2$. Therefore M3 will try to conduct less than IB. This leads to a decrease in voltage on the R contact of the Hall device until $VH1$ equals $Vref$.

Hence it is shown that the second desired factor of holding the Hall device centred on $Vref$ is achieved by the second half of the circuit.

The factor K is typically 1/10 which helps reduce the overall current consumption of the circuit.

The claims defining the invention are as follows:

1. An electricity measurement apparatus comprising supply means operative to supply a rectified A.C. supply signal to a sensor, the sensor being operative to detect magnetic field strength due to A.C. electricity flow along a conductor and to provide an output signal dependent on detected field strength and the
5 rectified A.C. supply signal, the output signal following a sine-squared relation with alternating positive and negative sign in each half cycle, and filtering means operative to remove a component due to a D.C. offset error from the output signal, in which the sensor output signal is maintained so that its amplitude midpoint is at least
10 approximately at a reference signal level midway between minimum and maximum possible amplitudes of the output signal.
2. An electricity measurement apparatus according to claim 1, in which the rectified A.C. supply signal is a rectified A.C. current signal.
- 15 3. An electricity measurement apparatus according to claim 1 or claim 2, in which the filtering means comprises a capacitor.
4. An electricity measurement apparatus according to any preceding
20 claim, in which components due to D.C. offset errors cancel.
5. An electricity measurement apparatus according to any preceding claim, in which the sensor is a Hall sensor.
- 25 6. An electricity measurement apparatus according to any preceding claim, in which the

rectified A.C. supply signal to the sensor is proportional to the electricity mains supply voltage.

7. An electricity measurement apparatus according to any preceding claim, in which the output signal from a sensor is a voltage signal.

8. An electricity measurement apparatus according to any preceding claim, in which the A.C. electricity flowing along the conductor is an electricity mains supply current.

9. A method of measuring electricity flow along a conductor including the steps of supplying a rectified A.C. supply signal to a sensor, the sensor detecting magnetic field strength due to A.C. electricity flow along a conductor and providing an output signal dependent on detected field strength and the rectified A.C. supply signal, the output signal following a sine-squared relation with alternating positive and negative sign in each half cycle, and filtering to remove a component due to D.C. offset error from the output signal, in which the sensor output signal is maintained so that its amplitude midpoint is at least approximately at a reference signal level midway between minimum and maximum possible amplitudes of the output signal.

10. A method according to claim 9, in which the filtering is undertaken by a capacitor.

11. A method according to claim 9 or claim 10, in which the sensor is a Hall effect device.

12. An electricity measurement apparatus substantially as herein described
with reference to Fig. 1.

13. A method of measuring electricity flow along a conductor
5 substantially as herein described with reference to Fig. 1.

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Horstmann Timers & Controls Limited

Patent Attorneys for the Applicant

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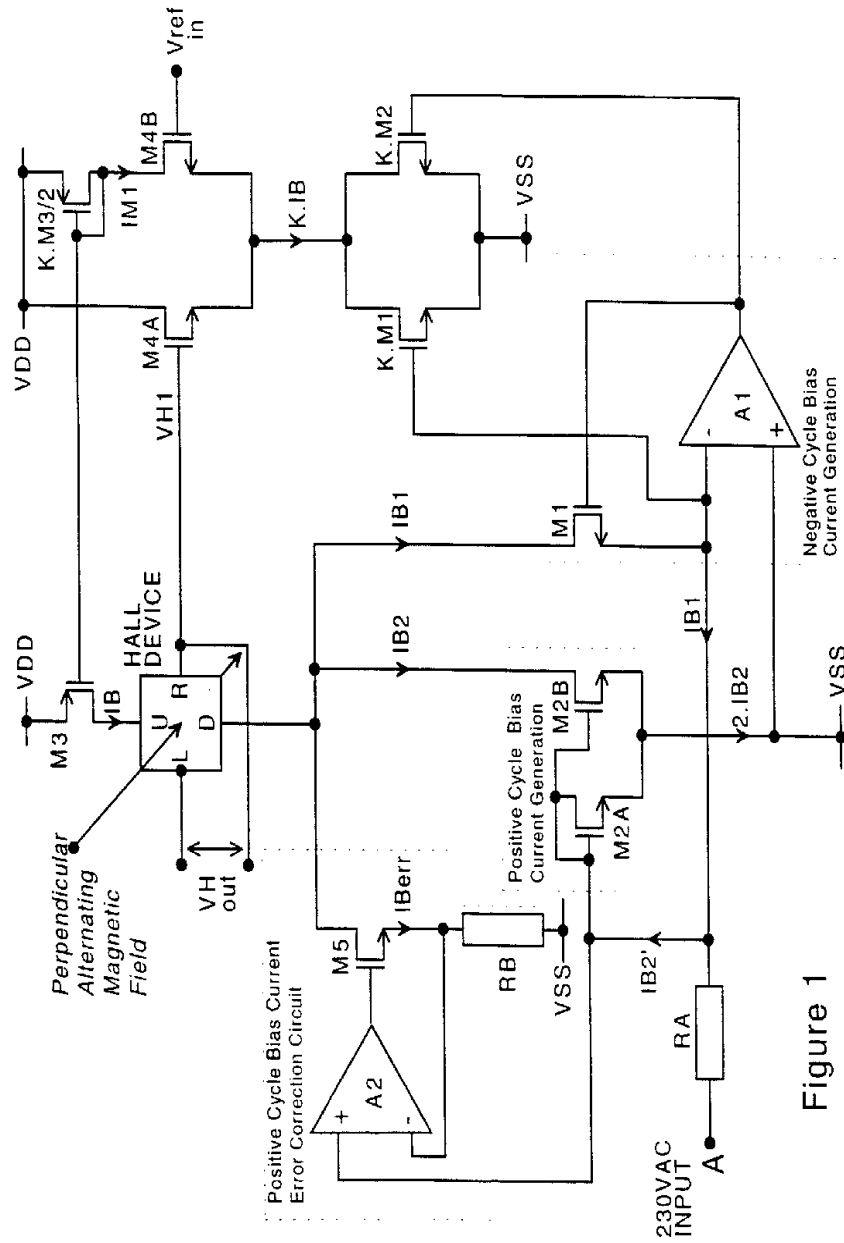


Figure 1

Modified Hall bias current generator

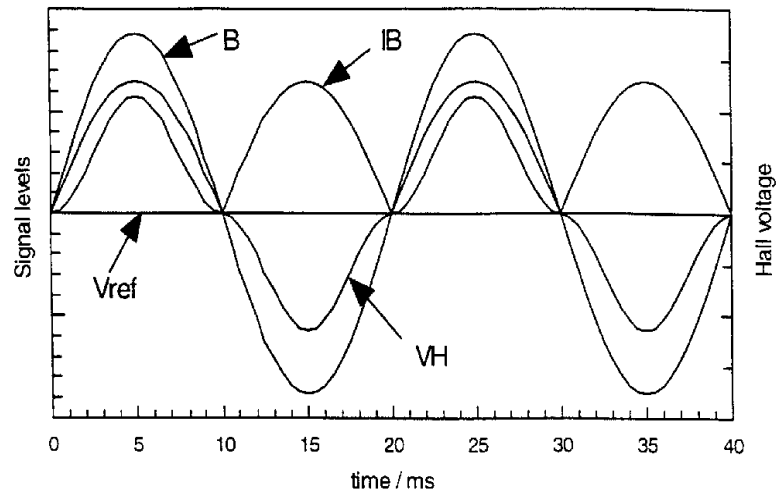


Figure 2

Standard Hall bias current generator

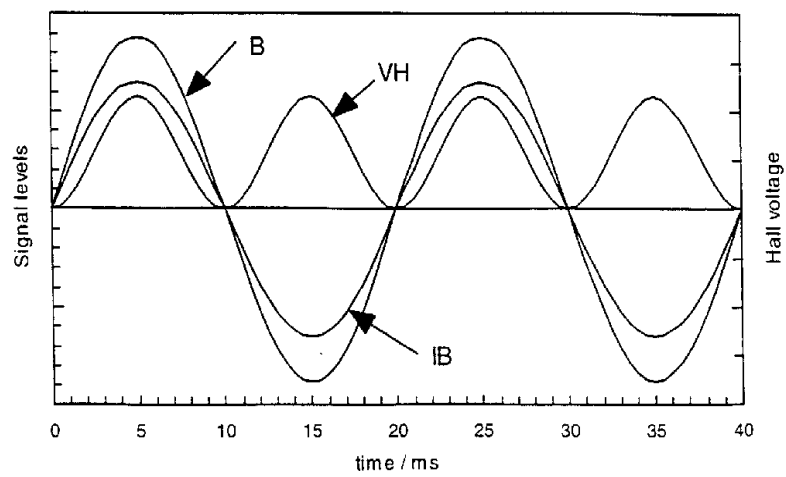


Figure 3 (Prior art)