Title: A SWITCH MODE POWER SUPPLY

Abstract: A current sensing circuit supplies an accurate sense signal (CMIa) representing a varying momentary current (Isa) flowing through a sense impedance (Rsa). The signal which represents the current (Isa) to be sensed is called the momentary information (Mia) to indicate that the momentary shape of the current (Isa) to be sensed should be preserved as much as possible. A gain stage or multiplier (GSI) corrects the amplitude of the momentary information (Mia) with a correction signal (CIS) to obtain corrected momentary information (CMIA). The corrected momentary information (CMIA) is the output signal of the current sensing circuit and represents the accurate sense signal. The correction signal (CS) is obtained by comparing a first voltage (Vr) across a reference impedance (Rr) and a second voltage (Ve) across a second impedance (Rc) which is correlated with the sense impedance (Rsa). The first voltage (Vr) is obtained by supplying a first current (I1) to the reference impedance (Rr). The second voltage (Ve) is obtained by supplying a second current (I2) to the second impedance (Rc). The correction factor (CS) controls a ratio between the first current (I1) and the second current (I2) until a desired ratio between the first voltage (Vr) and the second voltage (Ve) is obtained.
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A switch mode power supply

The invention relates to a current sensing circuit, a current-controlled switched mode power supply, an integrated circuit, and an electronic apparatus.

The integrated VRM controller from Semtech, commercially available under type number SC2433, operates in current control mode. This controller is able to operate several down-converters in parallel. The on-times of the different down-converters are shifted with respect to each other such that each of them supplies current to the load during periods in time shifted with respect to each other. This minimizes the ripple of the output voltage.

The current in the inductors is sensed with a single sense resistor in the 12V input line of the VRM. When no overlap of the phases of the different down-converters occurs, the single sense resistor provides information about the current flowing during the successive phases. This provides inherently good load sharing combined with over-current protection. Each of the down converters comprises a control FET and a FET operated as a synchronous rectifier (also referred to as sync FET) of which the main current paths are arranged in series to receive a DC-input voltage. An inductor is connected between the junction of the main current paths and the output load. The control FET is arranged between the DC-input voltage and the inductor. The use of a single current sense resistor in the power supply input line allows for an accurate measurement of the value of the current in the input line. However, the shape of the current in the input line shows very steep and large steps when the control FET or the sync FET is switched. The parasitic inductance of the sense resistor introduces error voltages which are difficult to filter. In addition the relatively long distance from the drains of the control FETs to this single sense resistor introduces large parasitic inductances, which causes a high amount of ringing.

In the sensing of the momentary current, these error voltages cause an inaccurate control of the power converter leading to disturbances of the output voltage.

It is an object of the invention to provide accurate momentary current sensing.
A first aspect of the invention provides a current sensing circuit as claimed in claim 1. A second aspect of the invention provides a current-controlled switched mode power supply as claimed in claim 12. A third aspect of the invention provides an integrated circuit as claimed in claim 18. A fourth aspect of the invention provides an electronic apparatus as claimed in claim 19. A fifth aspect of the invention provides an electronic apparatus as claimed in claim 20. Advantageous embodiments in accordance with the invention are defined in the dependent claims.

The current sensing circuit in accordance with the first aspect of the invention has to supply an accurate sense signal representing a varying momentary current flowing through a sense impedance. The signal which represents the current to be sensed is called the momentary information to indicate that the momentary shape of the current to be sensed should be preserved as much as possible. A gain stage or multiplier corrects the amplitude of the momentary information with a correction factor to obtain corrected momentary information. The corrected momentary information is the output signal of the current sensing circuit and represents the accurate sense signal which is referred to as the accurately sensed momentary current. The correction factor depends on a correction signal which is obtained by comparing a first voltage across a reference impedance and a second voltage across an impedance which is correlated with the sense impedance. The reference voltage is obtained by supplying a first current to the reference impedance. The voltage across the correlated impedance is obtained by supplying a second current to this impedance. The correction signal is used to vary a ratio of the first current and the second current to obtain a desired ratio between the first voltage and the second voltage. The correction signal is also fed to the multiplier to correct the amplitude of the momentary information with a factor depending on the correction signal.

The current sensing circuit controls the first and/or the second current until the voltages across the correlated impedance and the reference impedance have the predetermined desired relation. For example, if the comparator is an operational amplifier, the first and/or the second current is controlled until the first and the second voltage are substantially identical. The correction signal obtained in this steady state of the control loop depends on the actual impedance value of the correlated impedance. Thus, if the correlated impedance shows a spread in nominal value, or has a temperature dependency, the correction signal indicates the difference between the actual value of the correlated impedance with respect to its nominal value. Because the correlated impedance is correlated with the sense impedance, the value of the correlated impedance varies substantially synchronously with the
value of the sense impedance. Consequently, the correction signal corrects the momentary information to obtain the corrected momentary information, the amplitude of which is kept at the value which would be obtained if the value of the sense impedance were stable, which is not the case, and equal to its nominal value.

The sense impedance can be positioned such that the current to be sensed flows in a short loop, and that the sense circuit is connected by short tracks across the sense impedance to obtain a minimal influence of parasitics. The correlated resistor may receive a current which can be optimally selected, thus it is not a problem if the correlated impedance is positioned relatively far from the multiplier which supplies the corrected current to the correlated impedance. For example, the current through the correlated resistor may be a DC-current.

In the prior art approach, the varying momentary current is sensed as a voltage across an accurate sense resistor. The sense resistor has a parasitic behavior which causes the sense voltage across the sense resistor to deviate from the current through the sense resistor, even if the nominal value of the sense resistor is very accurate. This is true in particular if a large, rapidly varying current has to be sensed, such as, for example, in switched mode power converters. Consequently, the sense resistor which should have a low resistance value to prevent disturbance of the operation of the circuit whose current is sensed still has a significant size. In high current applications, such a large sense resistor has a relatively high parasitic series inductance. The sense voltage across the sense resistor may be unacceptably high because of this series inductance. Usually, the momentary shape of the current is required in the circuit in which the current is sensed. For example, the sensed voltage may be used to regulate a power converter. It is not possible to average the sense voltage to obtain a better average value of the current through the sense resistor because the required momentary information in the current would then be lost. Further, the nominal value of the sense resistor should be accurately determined (?) and not change in time or with temperature.

In an embodiment in accordance with the invention as claimed in claim 2, the current through the correlated impedance is controlled in response to the correction signal until the voltages across this correlated impedance and the reference impedance have the predetermined desired relation. Again, for example, if the comparator is an operational amplifier, the current through the correlated impedance is controlled until the first and the second voltages are substantially identical.

Thus, the sense circuit in accordance with this embodiment of the invention comprises a separate adjustment signal circuit and a slave circuit in the signal path of the
current to be sensed. A slave circuit in this context is a controllable circuit of which the control signal is generated by the adjustment signal circuit. The adjustment signal circuit comprises the reference impedance, the correlated impedance, a multiplier arranged in series with the correlated impedance to supply a corrected current to the correlated impedance, the current sources which supply the first current to the reference impedance and a related second current to the multiplier, and an operational amplifier or comparator which compares the first and second voltages to generate the correction signal. The slave circuit comprises a further multiplier which multiplies the sensed momentary information with a correction factor dependent on the correction signal. The accuracy of the corrected momentary information is best if the behavior of the correlated impedance is identical to the behavior of the sense impedance.

In an embodiment in accordance with the invention as claimed in claim 3, the current through the reference impedance is controlled in response to the correction signal until the voltages across the correlated impedance and the reference impedance have the predetermined desired relation. Again, for example, if the comparator is an operational amplifier, the current through the correlated impedance is controlled until the first and the second voltages are identical.

In an embodiment in accordance with the invention as claimed in claim 4, the comparator compares the first and the second voltages to obtain a difference. A loop filter, which usually is a low pass filter or an integrator, receives the difference and supplies the correction signal to the multiplier. The multiplier influences the first and/or the second current. This multiplier may be a separate multiplier arranged in series with one of the current sources, but the multiplier may also be incorporated in the current source. The correction factor of the multiplier depends on the correction signal which is obtained by integrating the difference of the first voltage and the second voltage. The first current has a predetermined relation with the second current. For example, the first current and the second current have a fixed ratio which may be one.

In an embodiment in accordance with the invention as defined in claim 5, in the adjustment signal circuit, the reference current and the current supplied to the multiplier have a ratio which can easily be obtained by a current mirror. Preferably, the ratio of both currents is determined by integers. Preferably, the current mirror is constructed to obtain a ratio of both currents which is independent of temperature and supply voltages.

In an embodiment in accordance with the invention as defined in claim 6, the reference impedance has an accurate nominal value. This has the advantage that a voltage
across the correlated impedance is compared with a very accurate voltage across the reference impedance, resulting in an improvement of the current sensing accuracy of the current to be sensed.

In an embodiment in accordance with the invention as defined in claim 7, the correlated impedance is matched with the sense impedance, which means that the correlated impedance and the sense impedance have correlated properties. This has the advantage that the variation of the sense impedance follows substantially one to one the variation of the correlated impedance. Consequently, the amplitude of the sensed current through the sense impedance (the momentary information) is corrected to be substantially independent of the actual value of the sense impedance. It is thus not required to use an accurate resistor as the sense impedance. By matched is meant that the properties of the correlated impedance and the sense impedance are substantially equal. For example, the sense impedance may be the drain-source impedance of a field effect transistor (further referred to as FET) through which the current to be sensed flows, a resistance of tracks on a printed circuit board, or tracks and/or bond wires of an integrated circuit. The correlated impedance may be the drain-source impedance of a FET which may be much smaller in size than the sense FET, or a track on the printed board, or tracks and/or bond wires of an integrated circuit.

In an embodiment in accordance with the invention as defined in claim 8, the correlated impedance is of the same type as the sense impedance to obtain a maximum correlation between their values. For example if the sense impedance is the drain-source impedance of a FET, the correlated impedance is the drain-source impedance of a similar FET whose dimensions may be smaller.

In an embodiment in accordance with the invention as defined in claim 9, the correlated impedance is positioned adjacent to the sense impedance. This improves the correlation between the value of the correlated impedance and the sense impedance with respect to their temperature. If both impedances are integrated, usually as resistors, the adjacent positioning further provides the highest possible correlation of their properties.

In an embodiment in accordance with the invention as defined in claim 10, the current to be sensed is a current through a switch which is a field effect transistor. The sense impedance is the drain-source impedance of this field effect transistor.

In an embodiment in accordance with the invention as defined in claim 11, two different currents have to be sensed to obtain a first and a second momentary information which represent the momentary values of the two currents to be sensed, respectively. The first momentary information is multiplied by a factor which depends on the correction signal
and the second momentary information is multiplied by a further factor which depends on the correction signal. The further factor may differ from the first mentioned factor. This has the advantage that only a single reference impedance and a correlated impedance are required. The sensing of the two currents may be inaccurate, for example the drain-source impedances of field effect transistors may be used. Preferably, the single reference impedance is a very accurate resistor. The number of required accurate resistors decreases because it is not required to use an accurate resistor for each of the currents to be sensed. This reference sense impedance is inexpensive if a DC-current flows through it. It is possible to use the single reference impedance also if more than two inaccurately sensed currents have to be corrected to obtain substantially accurate amplitudes of these currents to be sensed. The factors may comprise a fixed part and a part which is controlled by the correction signal, or they may be controlled completely by the correction signal, i.e. the fixed part is not present. The factors may be equal; in this case both the first and the second momentary information are each multiplied with the same factor.

In an embodiment in accordance with the invention as defined in claim 13, the sense circuit is incorporated in a down-converter wherein a series arrangement of the main current paths of a control FET (field effect transistor) and a sync FET receive a DC-input voltage. Such a down-converter is well known per se from the prior art. Either the regulation of the down-converter is improved because the current is sensed more accurately or the sensing of the current is less expensive because a simple inaccurate sense impedance can be used in the current path of the current to be sensed, or both. This is important because it is difficult and expensive to create a sense resistor of a very low value, which is able to withstand a high power, and which has a very low parasitic inductance. The series inductance of the reference impedance, which usually is a resistor, is hardly relevant because the reference current is preferably a DC current. It is not required to have an extremely low value of the reference resistor because this resistor is not in the current path of the circuit in which the current has to be sensed. The reference current may be small to obtain a low power dissipation in the reference resistor. The correlated impedance is not a difficult and expensive impedance either. The current through the correlated impedance may be small, and also may be a DC-current. In integrated circuits, it is relatively easy to match the correlated impedance and the sense impedance. If discrete resistors are used for the correlated impedance and the sense impedance, preferably, the same types are used, and preferably, these resistors are adjacentely positioned such that their temperature is substantially identical. Since the control loop has to adapt only to initial errors and temperature variations, the amplifier which
compares the voltages across the reference resistor and the correlated impedance preferably has a high gain and a low offset, but requires only a low bandwidth and thus can be designed by known offset reduction techniques such as chopping, dynamic element matching, large transistor size (7) etc. It is also possible to use a single amplifier which is subsequently coupled to receive both voltages, as a result of which the effect of the offset of this amplifier is cancelled.

In an embodiment in accordance with the invention as defined in claim 14, the sense impedance is the already present drain-source impedance of one of the FETs. This has the advantage that an extra resistor is not required.

In the drawings:

Fig. 1 shows a block diagram of a current sensing circuit in accordance with an embodiment of the invention,

Fig. 2 shows a block diagram of a consumer electronics apparatus having a current controlled switched mode power converter with a current sensing circuit in accordance with an embodiment of the invention, and

Fig. 3 shows a block diagram of a current sensing circuit in accordance with an embodiment of the invention.

Fig. 1 shows a block diagram of a current sensing circuit in accordance with an embodiment of the invention. Two currents $I_{sa}$ and $I_{sb}$ have to be sensed accurately. The current $I_{sa}$ flows through the sense impedance $R_{sa}$, the current $I_{sb}$ flows through the sense impedance $R_{sb}$. Preferably, the sense impedances $R_{sa}$ and $R_{sb}$ are resistances. For example, the sense impedances $R_{sa}$ and $R_{sb}$ are discrete resistors, resistors in an integrated circuit, drain-source resistances of FETs which preferably are integrated, or the resistance of tracks on a printed board or in an integrated circuit. The tracks in the integrated circuit may be or may include bond wires. The current sources FCS and SCS may draw their currents from a power supply voltage $V_{dd}$.

A sense circuit SCA, which usually is an amplifier, senses the voltage across the sense impedance $R_{sa}$ and supplies the momentary information $M_{ia}$. The momentary information $M_{ia}$ indicates the voltage across the sense impedance $R_{sa}$ and thus is a representation of the current $I_{sa}$ through the sense impedance $R_{sa}$. However, this
representation of the current Isa is not accurate due to spread of the nominal value and
temperature dependency of the sense impedance Rsa.

A sense circuit SCb, which usually is an amplifier, senses the voltage across
the sense impedance Rsb and supplies the momentary information Mlb. In the same manner
as discussed with respect to the sense circuit SCa, the voltage sensed over the sense
impedance Rsb is not an accurate indication of the current flowing through the sense
impedance Rsb.

The inaccurate momentary information Mla is multiplied by a factor which
depends on the correction signal CS to obtain a corrected momentary information CMIa
which is a better copy of the current Isa through the sense impedance Rsa. The inaccurate
momentary information Mlb is multiplied by a factor which depends on the correction signal
CS to obtain a corrected momentary information CMIb which is a better copy of the current
Isb through the sense impedance Rsb. The multiplication factors may be equal to the factor
indicated by the correction signal, but may also comprise a fixed part and a part determined
by the multiplication signal CS. The multiplication factors may also be different, for example
the momentary information Mla may be multiplied by 2 times the factor indicated by the
correction signal CS, while the momentary information Mlb is multiplied by 3 times the
factor indicated by the correction signal CS.

The inaccurate momentary information Mla, Mlb, and the corrected
momentary information CMIa, CMIb may be currents, voltages, or, in a digital
implementation, numbers. In an analog implementation, the sense circuits SCa, SCb may be
amplifiers. In a digital implementation, the sense circuits SCa, SCb may comprise analog to
digital converters. In the digital implementation, the correction signal may be a number.

The correction signal CS is determined by an adjustment signal circuit which
is elucidated in the following. A current source FCS supplies a current I1 to a reference
impedance Rr to obtain a reference voltage Vr across the reference impedance Rr. Preferably,
the reference impedance Rr is a resistance. A current source SCS supplies a current I2 to a
multiplier GS1 which receives the correction signal CS and supplies a corrected current kl2
which is the current I2 multiplied by a correction factor depending on the correction signal
CS. The corrected current kl2 flows through an impedance Rc to obtain a voltage Vc across
this impedance Rc. An amplifier or comparator COM compares the voltages Vr and Vc to
obtain a difference DI. The difference is integrated by the integrator or loop filter LF to
obtain the correction signal CS. Again, depending on the implementation, the difference DI
and the correction signal CS may be currents or voltages, or digital representations thereof.
Also the multipliers GS1, GSa, GSb may be analog multipliers or the multiplications may be obtained by multiplying numbers. Analog as well as digital implementations of the control loop involve a control action that makes the input signal of the comparator COM substantially equal by varying the transfer of the multiplier GS1.

The impedance Rc is also referred to as the correlated impedance Rc. By correlated is meant that this impedance Rc is correlated with one or both sense impedances Rsa, Rsb. The better the correlation is, the more accurately the corrected momentary information CMIa, CMIb represents the currents Isa, Isb.

The correlation may be obtained by using the same type of impedance for the correlated impedance Rc and the sense impedances Rsa, Rsb. For example, if the sense impedances Rsa, Rsb are drain-source paths of field effect transistors (further referred to as FET) the correlated impedance Rc also is a drain-source path of a FET. Or, if the sense impedance is a track of a printed board or integrated circuit, the correlated impedance also is a track, preferably having the same sheet resistance. The correlation may be improved by positioning the correlated impedance Rc adjacent to at least one of the sense impedances Rsa, Rsb. This improves the correlation with respect to the temperature behavior of the impedances. Further, in an integrated circuit the close proximity provides more identical nominal characteristics of the correlated impedance Rc and the sense impedances Rsa, Rsb. A very good correlation is obtained if the correlated impedance Rc and the sense impedances Rsa, Rsb are matched. The matching of impedances in an integrated circuit is well known per se.

The current sensing circuit controls the current I2 with the correction signal CS to obtain a corrected current kI2 through the correlated impedance Rc. The amplifier COM adapts the signal DI until the voltage Vc across this correlated impedance Rc and the voltage Vr across the reference impedance Rr are substantially equal. The integrator or loop filter LF serves for loop stability and suppression of noise on the control signal CS which causes variation of the gain of the multiplier GS1. A digital implementation of such a control loop can also be conceived, e.g. by increasing or decreasing a multiplication factor dependent upon the comparison of both signals supplied to a comparator COM. In this case, the loop filter LF may include a counter of which the content determines the multiplication factor of a multiplier. The correction signal CS obtained in the steady state of the control loop when the voltages Vc and Vr are substantially equal, depends on the actual impedance value of the correlated impedance Rc. Thus, if the correlated impedance Rc has a spread in its nominal value, or has a temperature dependency, the correction factor CS indicates the difference
between the actual value of the correlated impedance $R_c$ with respect to its nominal value. Because the correlated impedance $R_c$ is correlated with the sense impedance $R_{sa}$, $R_{sb}$, the value of the correlated impedance $R_c$ varies substantially synchronously with the value of the sense impedance $R_{sa}$, $R_{sb}$. Consequently, the corrected momentary information CMIa, CMIb has an amplitude which is kept at the value which would be obtained if the value of the sense impedance $R_{sa}$, $R_{sb}$ were stable and equal to its nominal value, in spite of the fact that the actual value of the sense impedance $R_{sa}$, $R_{sb}$ may differ from its nominal value.

It has to be noted that the adjustment signal circuit, which generates the correction factor $CS$, may be used to correct a single current sensing, or more than two different sensed currents. If more than one sensed current is corrected, only one adjustment signal circuit is required. The adjustment signal circuit is simple because the currents in this circuit may be small and thus the reference impedance may be simple. Preferably, the different sense impedances are correlated optimally with the correlated impedance. Preferably matched impedances are used. The matching of components in an IC is very well known per se.

Fig. 2 shows a block diagram of a consumer electronics apparatus having a current-controlled switched-mode power converter with a current sensing circuit in accordance with an embodiment of the invention.

The switched mode power converter is a down-converter with a control switch $SW_2$ and a sync switch $SW_1$, which are controlled by a switch controller 10 to have disjunct on-times. Usually, when the switch $SW_2$ is closed, the switch $SW_1$ is opened, and when the switch $SW_1$ is opened the switch $SW_2$ is closed. Thus, a non-inverted control signal $Q$ is supplied to the control input of the control switch $SW_2$ and an inverted control signal $Q_i$ is supplied to the control input of the sync switch $SW_1$. The controller 10 uses the corrected information CMI to regulate the power converter by determining on-times of the control switch $SW_2$ and the sync switch $SW_1$. Usually, the controller 10 requires further information, such as the output voltage $V_o$, to be able to regulate the power converter. Fig. 2 shows that both the control switch $SW_2$ and the sync switch $SW_1$ are FETs. The main current paths of the FETs $SW_1$, $SW_2$ are arranged in series to receive the DC-input voltage $V_i$. An inductor $L$ is arranged between a junction of the main current paths and the output of the power converter. A current $I_L$ flows through the inductor $L$. The power converter supplies an output voltage $V_o$ to a parallel arrangement of a smoothing capacitor $C_o$ and a load $L_o$, which is a circuit of the consumer electronics apparatus.
The actual momentary current $I_c$, is in the power converter is measured by sensing the drain source voltage of one of the switching FETs SW1, SW2. In Fig. 2 is shown that the drain source voltage of the sync FET SW1 is sensed, which is advantageous when the on-period of this sync FET SW1 is relatively long compared to the on-period of the control FET SW2. The sense circuit SC supplies the momentary information MI which represents the sensed drain source voltage. The multiplier GS multiplies the momentary information MI with the correction signal CS to compensate for the tolerance of the drain source impedance $R_{ds-on}$ of the FET SW1. The output signal of the multiplier GS is the accurate corrected momentary information CMI which is used by other circuits such as the switch controller to regulate the power converter.

Fig. 2 further shows the correlated impedance $R_c$ as the drain source impedance $R_{ds-on}$ of a FET SW3. The corrected current $kI_2$ flows through this drain source impedance $R_{ds-on}$. The FET SW3 is positioned near to the sync FET SW1 across which the voltage is sensed which represents the current is to be sensed to indicate that the FET SW3 is correlated with the FET SW1 such that their impedance values are linked.

Fig. 3 shows a block diagram of a current sensing circuit in accordance with an embodiment of the invention. The block diagram shown in Fig. 3 is based on the block diagram shown in Fig. 1. The same references are used for the same items. The current sensing circuits comprising the sense impedances $R_{sa}$, $R_{sb}$, the sense circuits SCa, SCb, and the multipliers GSa, GSb are not shown. Further differences are that the multiplier GS1 in series with the impedance $R_c$ of Fig. 1 is replaced by the multiplier GS2 in series with the impedance $R_r$. Further, the rail to which both the impedances $R_c$ and $R_r$ are connected is not floating but connected to a reference voltage $V_{cc}$ which, in this embodiment, has a value lower than the power supply voltage $V_{dd}$. The floating line in Fig. 1 indicates that it is not relevant for the circuit which exact voltage is present on this line.

In Fig. 3 the control signal CS controls the multiplier GS2 to multiply the current $I_1$ with a factor depending on the level or value of the control signal CS to obtain a corrected current $kI_1$ which flows through the impedance $R_r$. Preferably, the impedances $R_r$ and $R_c$ are resistances.

The operation of the circuit shown in Fig. 3 is the same as the operation of the circuit shown in Fig. 1. Because the comparator compares the difference of two voltages, it does not matter for the operation of the circuit whether the voltage across the impedance $R_r$ or the impedance $R_c$ is changed, or both. Further, it is not required that a multiplier is used to
vary the current I1 and/or I2 by the correction signal CS. The correction signal may also
directly influence the current sources FCS and/or SCS.

It should be noted that the above-mentioned embodiments illustrate rather than
limit the invention, and that those skilled in the art will be able to design many alternative
embodiments without departing from the scope of the appended claims.

Although the current sense circuit, when used in a power converter, is shown
to be combined with a down converter with a control switch SW2 and a sync switch SW1,
the current sense circuit in accordance with the invention can be implemented in any power
converter in which accurate sensing of a current is required. It must be understood that the
invention is applicable independent of the control principle of the power converter or the
output variable that needs to be controlled. Further, the current sensing is not limited to
application in a power converter.

The current sense circuit may be implemented with analog circuits, digital
circuits, or a suitably programmed computer or processor. The multipliers multiply the input
signal with a factor which depends on the correction signal. In an analog implementation,
usually, the multipliers are gain stages of which the gain is changed with the correction signal
CS. With the application of digital implementation techniques, a microprocessor may
actually multiply numbers or may control a gain stage to change its gain factor. Alternatively,
the comparator may be implemented in any digital form. For example, the comparator may
indicate whether the voltage across the impedance Rr is larger or smaller than the voltage
across the impedance Rc to increase or decrease, respectively, a count of a counter. Also the
loop filter may be a digital circuit or its function may be performed by a suitably
programmed computer.

In the claims, any reference signs placed between parentheses shall not be
construed as limiting the claim. Use of the verb "comprise" and its conjugations does not
exclude the presence of elements or steps other than those stated in a claim. The article "a" or
"an" preceding an element does not exclude the presence of a plurality of such elements. The
invention may be implemented by means of hardware comprising several distinct elements,
and by means of a suitably programmed computer. In the device claim enumerating several
means, a number of these means may be embodied by one and the same item of hardware.
The mere fact that certain measures are recited in mutually different dependent claims does
not indicate that a combination of these measures cannot be used to advantage.
CLAIMS:

1. A current sensing circuit comprising:
   a sensing circuit (SCa; SC) for sensing a momentary varying current (Isa; Is)
   through a sense impedance (Rsa; Rds-on) to obtain momentary information (MIA; MI),
   a reference impedance (Rr), and a second impedance (Rc) being correlated
   with the sense impedance (Rsa; Rds-on),
   means for generating (I1, I2, GS1; I1, I2, GS2) a first current (I1) through the
   reference impedance (Rr) and a second current (I2) through the second impedance (Rc),
   a comparator (COM) for comparing a first voltage (Vr) across the reference
   impedance (Rr) with a second voltage (Vc) across the second impedance (Rc) to supply a
   correction signal (CS) to the means for generating (I1, I2, GS1; I1, I2, GS2) to vary the ratio
   of the first current (I1) and the second current (I2) to obtain a desired ratio between the first
   voltage (Vr) and the second voltage (Vc),
   a multiplier (GSa; GS) for multiplying the momentary information (MIA; MI)
   with a factor depending on the correction signal (CS) to supply corrected momentary
   information (CMIA; CMI).

2. A current sensing circuit as claimed in claim 1, wherein the means for
   generating (I1, I2, GS1) comprises:
   a first current source (FCS) for supplying the first current (I1),
   a second current source (SCS) for supplying the second current (I2) having a
   predetermined relation with the first current (I1), and
   a further multiplier (GS1) for multiplying the second current (I2) with a first
   factor depending on the correction signal (CS) to supply a multiplied second current (kI2) to
   the second impedance (Rc).

3. A current sensing circuit as claimed in claim 1, wherein the means for
   generating (I1, I2, GS2) comprises:
   a first current source (FCS) for supplying the first current (I1),
a second current source (SCS) for supplying the second current (I2) having a
predetermined relation with the first current (I1), and
a further multiplier (GS2) for multiplying the first current (I2) with a first
factor depending on the correction signal (CS) to supply a multiplied first current (kI1) to the
reference impedance (Rr).

4. A current sensing circuit as claimed in claim 2 or 3, wherein the comparator
(COM) is arranged for comparing the first voltage (Vr) and the second voltage (Vc) to obtain
a difference (DI), and wherein the current sensing circuit further comprises a loop filter (LF)
for filtering the difference (DI) to supply the correction signal (CS).

5. A current sensing circuit as claimed in claim 2 or 3, wherein the
predetermined relation between the first current (I1) and the second current (I2) is determined
by integers.

6. A current sensing circuit as claimed in claim 1, wherein the reference
impedance (Rr) has an accurate nominal value.

7. A current sensing circuit as claimed in claim 1, wherein the second impedance
(Rc) and the sense impedance (Rsa; Rds-on) have correlated properties.

8. A current sensing circuit as claimed in claim 1, wherein the second impedance
(Rc) is positioned adjacent the sense impedance (Rsa; Rds-on) to have substantially the same
temperature.

9. A current sensing circuit as claimed in claim 1, wherein the second impedance
(Rc) is of the same type as the sense impedance (Rsa; Rds-on) to have substantially the same
behavior.

10. A current sensing circuit as claimed in claim 1, further comprising a
semiconductor switch (SW1), a switch controller (10) for controlling said switch (SW1) to
obtain the momentary varying current (Is) through a main current path of said switch (SW1),
wherein said switch (SW1) comprises a field effect transistor, and the sense impedance (Rsa;
Rds-on) is an on-resistance (Rds-on) of the main current path of said field effect transistor (SW1).

11. A current sensing circuit as claimed in claim 1, further comprising:

5 a further sense impedance (Rsb) and a further sensing circuit (SCb) for sensing a further momentary varying current (Isb) to obtain further momentary information (Mlb), and

and

a third multiplier (GSb) for multiplying the further momentary information (Mlb) with a third factor depending on the correction signal (CS) to supply further corrected momentary information (CMlb).

12. A current-controlled switched mode power converter comprising:

an inductor (L), a switch (SW1) coupled to the inductor (L), a switch controller (10) for controlling the switch (SW1) to obtain a periodical current (IL) through

the inductor (L),

a sensing circuit (SCa; SC) for sensing a momentary varying current (Isa; Is) through a sense impedance (Rsa; Rds-on) to obtain momentary information (MIa; MI),

a reference impedance (Rr) and a second impedance (Rc) being correlated with the sense impedance (Rsa; Rds-on),

means for generating (I1, I2, GS1) a first current (I1) through the reference impedance (Rr) and a second current (I2) through the second impedance (Rc),

a comparator (COM) for comparing a first voltage (Vr) across the reference impedance (Rr) with a second voltage (Vc) across the second impedance (Rc) to supply a correction signal (CS) to the means for generating (I1, I2, GS1) to vary a ratio of the first current (I1) and the second current (I2) to obtain a desired ratio between the first voltage (Vr) and the second voltage (Vc),

a multiplier (GSa; GS) for multiplying the momentary information (MIa; MI) with a factor depending on the correction signal (CS) to supply corrected momentary information (CMIa; CMI).

13. A current-controlled switched mode power converter as claimed in claim 12, further comprising a further switch (SW2) having a main current path arranged in series with the main current path of the first mentioned switch (SW1), the series arrangement of said main current paths being arranged to receive a DC-input voltage (Vi), the inductor (L) being
arranged between an output of said power converter and a junction of said main current paths.

14. A current-controlled switched mode power converter as claimed in claim 12, wherein the first mentioned switch (SW1) comprises a field effect transistor, the sense impedance (Rs; Rds-on) being an on-resistance (Rds-on) of the main current path of said field effect transistor (SW1).

15. A current-controlled switched mode power converter as claimed in claim 14, wherein the second impedance (Rc) is an on-resistance (Rds-onc) of a main current path of a further field effect transistor (SW3).

16. A current-controlled switched mode power converter as claimed in claim 15, wherein the first mentioned field effect transistor (SW1) and the further field effect transistor (SW3) are matched.

17. A current-controlled switched mode power converter as claimed in claim 12, wherein the first current (I1) and the second current (I2) are DC-currents.

18. An integrated circuit comprising a current sensing circuit as claimed in claim 1.

19. An electronic apparatus comprising a current sensing circuit as claimed in claim 1.

20. An electronic apparatus comprising a current-controlled switched mode power converter as claimed in claim 12.
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC 7  H02M3/156

According to International Patent Classification (IPC) or to both national classification and IPC.

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC 7  H02M  GO1R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched:

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
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<tr>
<td>X</td>
<td>US 5 723 974 A (GRAY RICHARD L) 3 March 1998 (1998-03-03) abstract column 1, line 64 - line 67 column 3, line 26 - line 64 column 4, line 26 - line 55 figures 1-4</td>
<td>1-20</td>
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Further documents are listed in the continuation of box C.

**X** Patent family members are listed in annex.

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Date of the actual completion of the international search: 20 January 2005

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<th>Publication date</th>
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<tr>
<td>US 5723974 A</td>
<td>03-03-1998</td>
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