(54) Title: SWITCH MODE POWER SUPPLY CONTROLLERS
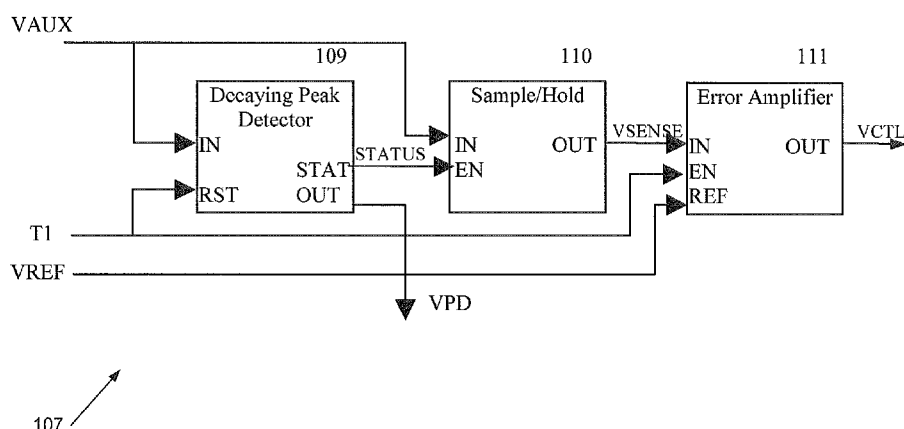
(57) Abstract: This invention relates to SMPS controllers employing primary side sensing. We describe a system for identifying a knee point in a sensing waveform, at which the output voltage of the SMPS may be sampled accurately on the primary side. The system identifies the knee point by fitting a tangent to a portion of a power transformer voltage waveform, and samples the voltage waveform at the knee point to determine the SMPS output voltage. In preferred embodiments this technique is implemented using a decaying peak detector, providing a timing signal indicating detection of the knee point. Sample/hold and error amplifier circuits may be employed to achieve output voltage regulation.

Switch Mode Power Supply Controllers

FIELD OF THE INVENTION

This invention generally relates to a switch mode power supply (SMPS) controllers and to related methods. More particularly it relates to SMPS controllers employing primary side sensing to detect in a sensing waveform, at which point the output voltage of the SMPS may be sampled on the primary side.

BACKGROUND TO THE INVENTION

Broadly speaking in a switch mode power supply a magnetic energy storage device such as a transformer or inductor is used to transfer power from an input side to an output side of the SMPS. A power switch switches power to the primary side of the energy storage device, during which period the current and magnetic field builds up linearly. When the switch is opened the magnetic field (and secondary side current) decreases substantially linearly (on average) as power is drawn by the load on the output side.

An SMPS may operate in either a discontinuous conduction mode (DCM) or in continuous conduction mode (CCM) or at the boundary of the two in a critical conduction mode. In DCM operating modes in which, when the switching device is turned off, the output voltage steadily, but gradually, declines until a point is reached on the knee of the output curve at which substantially zero output current flows and the inductor or transformer begins to ring, entering a so-called oscillatory phase. The period of the ringing is determined by the inductance and parasitic capacitance of the circuit. In this specification DCM includes so-called critical (discontinuous conduction) mode (CRM) operation in which the power switch is turned on again at the first trough of the oscillatory phase (sometimes referred to as the flyback oscillation). Operation in CRM can be particularly efficient by reducing losses associated with the power switch turn-off transition. In continuous conduction mode (CCM) the power switch is turned

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on to "recharge" the flux in the inductor or transformer for a subsequent cycle before the flux, and hence output current, has fallen to zero (so that the inductor or transformer is substantially always "on"). Embodiments of the techniques we describe are useful for all these three modes of operation.

Often the output voltage of an SMPS is regulated by sensing circuitry on the output side, coupled back to the input side of the SMPS by means of an opto-isolator. However some improved techniques employ primary side sensing or, more generally, sensing employing an auxiliary winding on the magnetic energy storage device, or in some related circuits an auxiliary winding of an output filter inductor.

Some background prior art relating to primary side sensing can be found in US6,958,920; US6,721,192; US2002/015315; WO2005/048442; WO2004/051834; US2005/0024898; US2005/0169017; US6,956,750; US6,862,198; US2006/0056204; US7,016,204; US2006/0050539; US2006/0055433; US2006/0034102; US6,900,995; US6,862,198; and US6,836,415. Still further background prior art can be found in US6385059, US20050276083, US6977824, US6956750, WO2004082119, US6972969, WO03047079, US6882552, WO2004112227, US2005285587, WO2004112226, WO2005011095, US6985368, US7027312, US6373726, US4672516, US6301135, US6707283, and US6333624.

Referring now to Figure 1, this shows an example of a switch mode power supply circuit with primary side sensing. The power supply comprises an AC mains input coupled to a bridge rectifier 14 to provide a DC supply to the input side of the power supply. This DC supply is switched across a primary winding 16 of a transformer 18 by means of a power switch 20, in this example an insulated gate bipolar transistor (IGBT). A secondary winding 22 of transformer 18 provides an AC output voltage which is rectified to provide a DC output 24, and an auxiliary winding 26 provides a feedback signal voltage proportional to the voltage on secondary winding 22. This feedback signal provides an input to a control system 28, powered by the rectified mains. The secondary winding is usually physically isolated from the primary winding (and auxiliary winding, if present) and their associated components to meet legislative requirements. The control system provides a drive output 30 to the power switching

device 20, modulating pulse width and/or pulse frequency to regulate the transfer of power through transformer 18, and hence the voltage of DC output 24. In embodiments the power switch 20 and controller 28 may be combined on a single power integrated circuit.

As can be seen, the primary side controlled SMPS of Figure 1 derives feedback information from the primary side of the transformer, using an auxiliary winding to avoid high voltage signals, the voltage being stepped down by the turns ratio of the transformer. As the skilled person will appreciate, however, it is not necessary to employ a separate auxiliary winding although this may be convenient if such a winding is already contemplated to provide a low voltage supply to the controller. For example, a voltage of the primary winding may be sensed, preferably capacitor coupled so that it can be referenced to the ground of the controller, and stepped down using a potential divider. An example circuit for this is shown inset in Figure 1, with a dashed connection to the primary winding 16. The skilled person will further appreciate that an auxiliary winding is not necessary to provide a dc supply for the controller as this may be derived from the high voltage dc supply on the primary side of the SMPS or in a number of other ways, for example using a capacitor charge pump driven via a diode from the switched voltage on the power switch. In some preferred implementations, therefore, the auxiliary winding is omitted.

We will describe techniques for using the transformer voltage waveform to generate feedback information for regulating an SMPS. These facilitate operation across a wide range of input and output conditions and, in embodiments, provide lower cost, inaudible operation and improved output regulation.

SUMMARY OF THE INVENTION

According to a first aspect of the invention there is therefore provided a system for sensing an output voltage of a switch mode power supply (SMPS), the SMPS including a switched magnetic energy storage device for conveying power from an input to an output of said SMPS, said magnetic device having at least one winding, the system

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comprising; an input to receive a sensing signal from said at least one winding of said magnetic device, said sensing signal having a waveform with a first, decaying portion during which power is supplied by said magnetic device to said SMPS output and a second portion during which substantially no power is supplied by said magnetic device to said SMPS output; a signal follower coupled to said input to generate a decay signal approximating said decaying portion of said sensing signal waveform; a comparator to compare said decay signal with said sensing signal waveform to identify when said sensing signal waveform decays faster than said decay signal; and a sampler to sample said sensing signal responsive to said comparator to provide an output signal sensing said output voltage of said SMPS.

The above described sensing system may be employed in an SMPS controller operating in either DCM/CRM mode or in CCM mode. In DCM/CRM mode the second portion of the feedback signal waveform comprises an oscillatory portion of the waveform (although not necessarily with a complete cycle of oscillation); in CCM mode the second portion of the waveform comprises a portion of the waveform during which input power is switched to the magnetic energy storage device.

In DCM/CRM embodiments the system may be employed to detect a point of substantially zero magnetic flux by detecting a knee in this sensing waveform between the decaying and oscillatory portions of the waveform. At this point the output voltage of the SMPS may be sampled accurately on the primary side since, because the secondary side current is substantially zero, there is substantially no voltage drop across the secondary side components, typically a diode and some series resistance.

In CCM embodiments the system can be used to determine when a power switching device switching input power to the magnetic energy storage device turns on. Typically such a power switching device comprises a bipolar or MOSFET switch which often has a small switching delay. By monitoring the sensing signal waveform the actual switching time of such a device can be established. Furthermore, it is desirable for a CCM mode SMPS controller to be able to control an SMPS in a DCM mode so that this mode can be employed at low load levels. Embodiments of the above described sensing system can be used in both DCM and CCM modes and thus a single, common

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sensing system can be used for an SMPS controller rather than having to switch between different sensing systems depending upon the operating mode of the SMPS. Embodiments of the sensing system provide such dual mode operation (triple mode, if CRM is considered as a separate mode).

Depending upon the SMPS implementation, for example where in DCM mode the oscillatory portion of the signal includes more than one cycle of oscillation, there may be more than one point when the sensing signal waveform decays faster than the decay signal. Preferably, therefore, the system also includes an enable input to receive an enable signal for disabling the operation of the sampler during the oscillatory portion of the sensing signal. The enable signal may disable the signal follower and/or comparator and/or may gate the comparator output; it may be derived from the sensing signal waveform or, for example, from a drive signal driving a power switching device of the SMPS.

In some preferred embodiments the signal follower comprises a decaying peak detector, to detect peaks of the sensing signal and to hold these with a decaying characteristic. In one embodiment the decaying peak detector comprises a rectifier coupled to capacitor, with a discharge circuit, such as a current generator, coupled across the capacitor. The comparator may have an offset built in to offset a voltage drop across the rectifier.

The sampler to sample the sensing signal responsive to the comparator may comprise a sample-hold circuit to sample and hold the sensing signal when the sensing signal waveform decays faster than the decay signal. The sensing signal may be sensed either directly or indirectly, for example by sensing the decay (the output of the decaying peak detector) which, until the sampling point, tracks the sensing signal. In other embodiments the sampler comprises an integrator to sample the sensing signal by integrating the sensing signal waveform from the point when the sensing signal waveform decays faster than the decay signal, to a later point on the sensing signal waveform, for example a zero-crossing of the sensing signal waveform. This integration gives a value which is dependent upon the amplitude of the signal at the knee point on the sensing signal waveform, and hence can be used to provide a control signal for controlling the SMPS. Further details of such an "area correlation" method

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are described in the assignee's co-pending patent application no. **XXX** filed on the same
day as this application, inventor Vinod A Lalithambika, [our ref: P290661], hereby
incorporated by reference in its entirety.

The invention further provides an SMPS controller including a sensing system as
described above and, in preferred embodiments, a comparator to compare the output
signal with a reference and to provide a control output for controlling a switch mode
power supply in response to the comparison. The comparator, in embodiments, may
comprise an error amplifier to provide an analogue error signal (albeit in embodiments
this may be represented in a digital form, though with multiple rather than just two
binary levels). Use of an analogue control signal facilitates stabilising the control loop
of the SMPS.

In another aspect the invention provides an SMPS controller for controlling the output
of an SMPS, the SMPS including a switched magnetic energy storage device for
conveying power from an input to an output of said SMPS, said magnetic device having
at least one winding, the controller comprising: a sense input to receive a sense signal
waveform from said magnetic device; a decaying peak detector coupled to said sense
input to detect when said sense signal waveform has a falling slope of greater than a
threshold value and to generate a first timing signal: an output to provide an SMPS
control signal responsive to a value of said sense signal waveform at a time indicated by
said first timing signal.

In embodiments the SMPS control signal is used to regulate an output voltage of the
SMPS, for example by controlling a pulse width and/or frequency of an oscillator
driving a power switch switching power to the magnetic energy storage device. In some
preferred embodiments the controller includes a timing signal input so that the SMPS
control signal output does not detect large negative slopes at peaks in a resonant,
oscillatory portion of the sense signal waveform. Preferably the controller includes a
sample-hold module to sample and hold the sense signal waveform in response to the
first timing signal. In implementations of the controller in an SMPS there may be
multiple subsidiary peaks in the generally linearly decaying portion of the sense signal
waveform and, therefore, the sample-hold module may, in embodiments, sample peaks

of this superimposed "noise", holding the last sample before the second timing signal indicates that substantially no power is being supplied by the SMPS, that is the last sample before the sampling is disabled by the second timing signal. In other embodiments an integration-based or "area correlation" sampling technique may be employed.

In a related method the invention provides a method of sensing an output voltage of a switch mode power supply (SMPS), the SMPS including a switched magnetic energy storage device for conveying power from an input to an output of said SMPS, said magnetic device having at least one winding, the method comprising: inputting a sensing signal from said at least one winding of said magnetic device, said sensing signal having a waveform with a first, decaying portion during which power is supplied by said magnetic device to said SMPS output and a second portion during which substantially no power is supplied by said magnetic device to said SMPS output; identifying a knee point said sensing signal waveform between said decaying portion and said second portion of said waveform; and using a value of said sensing signal at said knee point to sense said SMPS output voltage; and wherein said identifying of said knee point comprises fitting an approximate tangent to said decaying portion of said sensing signal waveform; and identifying departure of said sensing signal waveform from said approximate tangent to identify said knee point.

In embodiments the knee point on the sensing signal waveform corresponds to a point at which the secondary current has just dropped to substantially zero (at which point the voltage across a secondary winding may substantially equal an output voltage of the SMPS). It will be appreciated that the sensing signal will in general provide a signal which is proportional to the SMPS output voltage, for example as determined by a primary: secondary or auxiliary: secondary turns ratio of a transformer of the SMPS, rather than voltage which is exactly equal to the SMPS output voltage.

Some embodiments of the method may directly determine when the sensing signal waveform departs from the approximate tangent, by more than a threshold different in slope, to identify the knee point. However in some preferred embodiments when the method is operating (enabled) each departure of the sensing signal waveform, by greater

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than a threshold level, from the approximate tangent is detected and used trigger a sample (and hold) of the sensing signal (or a signal derived therefrom) until the second portion of the sensing signal waveform is reached, at which point the last detected departure, which was sampled (and held) provides a value of the sensing signal (or a signal derived therefrom) at the knee point. Alternatively an area integration method as indicated above may be employed, using the value of the sensing signal at the knee point by integrating the sensing signal waveform from the knee point to a later point to (indirectly) sense the SMPS output voltage.

In a further aspect the invention provides a method of sensing an output voltage of a switch mode power supply (SMPS), the SMPS including a switched magnetic energy storage device for conveying power from an input to an output of said SMPS, said magnetic device having at least one winding, the method comprising: inputting a sensing signal from said at least one winding of said magnetic device, said sensing signal having a waveform with a first, decaying portion during which power is supplied by said magnetic device to said SMPS output and a second portion during which substantially no power is supplied by said magnetic device to said SMPS output; identifying a knee point on said sensing signal waveform between said decaying portion and said second portion of said waveform; and using a value of said sensing signal at said knee point to sense said SMPS output voltage; and wherein said identifying of said knee point comprises detecting a point of greater than a threshold negative slope in said sensing signal waveform.

There is also provided a method of regulating the output voltage of an SMPS using an output voltage sensing method as described above. The regulating may, in embodiments, comprise comparing the sensed output voltage with a reference level to provide an error signal substantially proportional to the difference between the two, and using the error signal to control the SMPS.

In a still further aspect the invention provides a system for sensing an output voltage of an SMPS, the SMPS including a switched magnetic energy storage device for conveying power from an input to an output of said SMPS, said magnetic device having at least one winding, the system comprising: means for inputting a sensing signal from

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said at least one winding of said magnetic device, said sensing signal having a waveform with a first, decaying portion during which power is supplied by said magnetic device to said SMPS output and a second portion during which substantially no power; means for identifying a knee point on said sensing signal waveform between said decaying portion and said second portion of said waveform; and means for using a value of said sensing signal at said knee point to sense said SMPS output voltage; and wherein said means for said identifying of said knee point comprises: means for fitting an approximate tangent to said decaying portion of said sensing signal waveform; and means for identifying departure of said sensing signal waveform from said approximate tangent to identify said knee point.

The invention still further provides a system for sensing an output voltage of an SMPS, the SMPS including a switched magnetic energy storage device for conveying power from an input to an output of said SMPS, said magnetic device having at least one winding, the system comprising: means for inputting a sensing signal from said at least one winding of said magnetic device, said sensing signal having a waveform with a first, decaying portion during which power is supplied by said magnetic device to said SMPS output and a second portion during which substantially no power is transferred; means for identifying a knee point on said sensing signal waveform between said decaying portion and said second portion of said waveform; and means for using a value of said sensing signal at said knee point to sense said SMPS output voltage; and wherein said means for said identifying of said knee point comprises: means for detecting a point of greater than a threshold negative slope in said sensing signal waveform.

The skilled person will appreciate that the above-described techniques may be employed in a wide variety of SMPS architectures including, but not limited to, a flyback converter and a direct-coupled boost converter. In some implementations the magnetic energy storage device comprises a transformer with primary, secondary, and auxiliary windings but in other implementations an auxiliary winding may be provided on another inductor of the SMPS. In still other implementations an auxiliary winding may be omitted and the sensing signal derived from a primary winding, for example as described above with reference to Figure 1.

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In a further related aspect the invention provides a switch mode power supply including an SMPS controller as described above.

In some preferred embodiments a system or SMPS controller as described above is implemented mainly or entirely using analogue circuitry. This is because clocked digital systems can introduce higher costs, audible noise problems and output inaccuracies due to the time-quantisation effects of the digital sampling process.

In other embodiments, however, the system or SMPS controller may be implemented partially or wholly using digital circuitry. Thus the invention further provides a carrier medium carrying processor control code such as RTL or SystemC defining hardware to implements such circuitry.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the invention will now be further described, by way of example only, with reference to the accompanying figures in which:

Figure 1 shows an example of an SMPS incorporating primary side sensing.

Figure 2 shows a switch mode power supply (SMPS) including an SMPS controller according to an embodiment of the invention;

Figure 3 shows details of the voltage sensing block of the controller of Figure 2;

Figure 4 shows an example decaying peak detector for the voltage sensing block of Figure 3;

Figure 5 shows an example sample/hold module for the voltage sensing block of Figure 3;

Figure 6 shows an example error amplifier for the voltage sensing block of Figure 3;

Figure 7 shows waveforms illustrating the principle of operation of an SMPS controller according to an embodiment of the invention; and

Figure 8 shows example waveforms illustrating the operation of the SMPS controller of Figure 3.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Broadly speaking we will describe an apparatus and a related method for measuring an output voltage from a primary side of a power converter. A winding on the power transformer, such as a primary or auxiliary winding, provides a waveform to a peak detector with defined decay characteristic. The peak detector voltage thus forms a tangent to a selected portion of the auxiliary winding waveform. A status signal from the peak detector indicates the time(s) when the tangent coincides with (and departs from) the auxiliary winding waveform, thus in DCM/CRM providing an estimated instant when the transformer secondary winding current has dropped to zero. The status signal controls a sample/hold circuit, which at that instant captures a voltage reflecting a secondary voltage of the transformer, such as a voltage from the primary or an auxiliary winding of the transformer. In CCM essentially the same technique may be employed to determine when the (primary side) power switching device has turned on.

In embodiments an error amplifier compares the captured voltage against a reference to determine an error signal, preferably an analogue error signal, which may be used to regulate the power converter output voltage. The use of an analogue error signal allows the loop gain to be predicted accurately, facilitating loop compensation. Further analogue embodiments of the technique facilitate implementation of a controller with a low power consumption.

One difficulty in primary-side sensing, in particular when operating in DCM/CRM modes, is deciding exactly when to sample the reflected secondary voltage. Ideally this voltage should be sampled at the point at which the current in the secondary winding just falls to zero, as it is at this point that the sampled voltage most accurately represents

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the output voltage. This is because when the secondary current has just dropped to zero, there is no voltage drop across the secondary rectifier diode or its and the transformer's series resistance, and thus the voltage across the secondary winding is equal to the output voltage. The voltage across, say, the auxiliary winding is equal to the voltage across the secondary winding multiplied by the (known) turns ratio between the two windings, and the secondary voltage can thus be inferred by measuring the voltage across (say) the auxiliary winding at this point.

In CCM mode the secondary voltage can be sensed via a primary or auxiliary winding in a similar way to DCM mode except that the secondary voltage is sampled at a non-zero secondary side current. This non-zero (although sometimes small) current introduces a non-zero voltage drop across the secondary side components, which may comprise for example a diode and some output resistance. Thus preferably in CCM mode some compensation is made for the voltage drop from the secondary side winding to the SMPS output across these components. This compensation can be made, for example, based upon an approximate knowledge of the secondary side current, which can be inferred from the current in the primary side switch.

Referring now to figure 2, this shows a block diagram of a flyback single-switch SMPS 200 incorporating an embodiment of an SMPS controller according to the invention. As illustrated the controller is operating in the context of a flyback SMPS converter, but the skilled person will understand that the techniques we describe are also applicable to other forms of SMPS converters.

A DC source 100 is connected to the primary winding of a transformer in series with a primary side switch 106. The secondary winding of the transformer is connected to an output diode 101 in series with a capacitor 102. A load, represented by a resistor 103 is connected across the output capacitor 102. One end of an auxiliary winding on the transformer 104 is connected between the negative terminal of the DC supply 100 and the other end "VAUX" is connected to an Oscillator and Timing Block 105 and to a Voltage Sense Block 107.

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The Voltage Sense Block 107 generates a signal (or value) VCTL representing the required level of output power, from signals VAUX and T1. The VCTL signal is fed back to the Oscillator and Timing Block which generates a DRIVE pulse for switch 106 at an appropriate frequency and duration.

In embodiments the timing signal T1 is derived from the VAUX signal, providing the timing control for the Voltage Sense Block 107. Typically T1 is driven active shortly after VAUX goes positive (allowing time for the initial overshoot waveform artefacts to decay), for example based on a comparison of VAUX with zero or on the DRIVE signal. T1 may be driven inactive when VAUX goes negative again. For example, a comparator may be employed to identify a negative-going zero-crossing of VAUX to drive T1 inactive. Timing signal T1 may be generated either by oscillator block 105 or within voltage sensing block 107.

As previously mentioned, the Oscillator and Timing Block 105 uses the input VCTL to control the frequency and pulse duration applied to the DRIVE output, which controls the main primary switch 106. As the skilled person will understand, the Oscillator and Timing Block 105 may be implemented in many different ways; examples of some particularly advantageous techniques are described in the Applicant's patent applications US 60/698808 (0513772.4) and PCT/GB2005/050244, hereby incorporated by reference.

Before describing details of the voltage sensing module 107 we first refer to Figure 7 to describe the tangent-based method of output voltage sensing. The aim of the tangent method of output voltage sensing is to accurately detect the voltage in the transformer auxiliary winding at the knee point, that is the point at which the transformer secondary current drops to substantially zero, as shown in Figure 7.

The VAUX (sensing) signal from the primary or auxiliary winding of the power transformer typically appears as shown. This is a transform of the secondary winding, generally with superimposed artefacts generated by winding leakage inductance, stray capacitance, and the like. Broadly, the tangent method works by fitting a tangent with a negative slope to the flyback portion of the VAUX waveform. The tangent slope is

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chosen to optimise the accuracy of identifying the knee point and to ensure that the waveform artefacts have minimal influence. The VAUX signal is then sampled at the knee point and compared to a voltage reference to determine the output error voltage. A preferred practical implementation, as described below.

Referring now to Figure 3, this shows the main functional blocks of the Voltage Sensing circuit 107, which together comprise a decaying peak detector block 109, a sample/hold block 110 and an error amplifier block 111, generating the output signal VCTL (output voltage control). Typical waveforms are shown in Figure 8. The output VPD (voltage peak detect) from the decaying peak detector block 109 is not used in some embodiments; in others it may be used to sense or sample a value of VAUX since it approximately tracks VAUX during its approximately linearly decaying portion and is substantially equal to VAUX at the knee point.

Figure 4 shows an implementation of the decaying peak detector (DPD) block 109 of Figure 3.

Referring to Figure 4, the VAUX is fed into the input (IN) of the DPD block as shown. When timing signal T1 is inactive (low in Figure 8) the DPD is reset, forcing the output voltage VPD to 0 volts. As shown, T1 is active, and therefore switch S1 is closed and switch S2 is open so that the DPD is not reset. When T1 is active, the circuit works as a peak detector, providing output VPD which decays at a predetermined rate. Alternatively the peak detector may be free-running, in which case the EN signal may be gated by T1. As shown in Figure 8, VPD follows the VAUX waveform except when the slope of VAUX exceeds a certain (negative) value, at which point the VAUX and VPD waveforms separate from one another. The STATUS signal from the DPD is active when the DPD is updating (increasing) the VPD signal.

An example implementation for the decaying peak detector 109, shown as a behavioural model, is illustrated in Figure 4. A diode D1 and a capacitor C1 together comprise a peak detector; this is enabled when switch S1 is closed and S2 is open. A current sink I1 discharges the voltage on C1, thus defining the slope of the tangent. A comparator COMP1 compares the tangent approximating voltage on C1 with the VAUX input.

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Preferably a voltage source V1 adds a small DC offset compensating for the forward voltage drop of D1. Thus comparator COMP1 will issue a STATUS active if VAUX is greater than or equal to the (decaying) voltage on C1. Thus the DPD effectively detects when VAUX has greater than a threshold downwards or negative slope. The peak detector is re-initialised by the RST signal, closing switch S2 and opening switch S1, thereby discharging the voltage on capacitor C1. The rate of discharge of C1 is set by I1, which is chosen according to the implementation so that, in embodiments, the voltage on C1 follows the approximately linear descent of VAUX, that is so that it follows an approximate tangent to VAUX prior to its oscillatory or resonant portion.

An example implementation for the sample/hold module 110 is illustrated in Figure 5. Buffer BUF1, capacitor C2 and switch S3 together comprise a sample/hold circuit, which samples the VAUX input when EN is active and holds the sampled value when EN is inactive. Thus, the voltage output VSENSE holds the instantaneous value of VAUX when STATUS is driven inactive (at various points in the flyback phase and finally at the knee point), as shown in Figure 8.

An example implementation for the error amplifier module 111 is illustrated in Figure 6. Amplifier OP1, capacitor C1 and resistor R1 form a simple integrator, enabled by switch S4. While input EN is active, switch S4 is closed, enabling the amplifier OP1 to integrate the difference between VSENSE and VREF. The time constant is preferably at least several cycles of oscillator 105, for example around 10 cycles. In this way the accumulated error over many switching cycles may be used by the Oscillator and Timing Block to modify the delivered power and thereby regulate the output voltage. Those skilled in the art will appreciate that the resistor and capacitor shown may be replaced by a variety of different impedance networks, for example in order to compensate the control loop using, say, pole-cancellation techniques.

Referring back once more to Figure 7, it will be appreciated that it is desirable that the waveform to which the tangent-detection technique we have described is applied is relatively clean, and thus a modicum of filtering may be applied. Additionally or alternatively the waveform may be "qualified" to disable the operation of the tangent detection except in the vicinity of the knee point, for example by disabling the peak

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detector until a point close to the knee point is reached. This may be implemented, for example, by modelling the flux in the transformer by integrating the voltage on a primary or auxiliary winding of the transformer, more particularly by integrating the sensing signal, from a point of known zero transformer flux to determine a next point of zero transformer flux. This latter point corresponds to the knee on the primary or auxiliary winding sensing signal and hence the timing of this point may be used to define a window within which the tangent method should look at the sensing signal waveform, for example by enabling the peak detector over this time window. Points of known zero-transformer flux correspond to peaks and troughs on the oscillatory portion of the sensing signal waveform and thus, for example, the integrator may be reset at each of these peaks and troughs so that it is always reset at a point of known zero flux before the power switching device is switched on and the switching cycle begins. The peaks and troughs may conveniently be detected using a peak detector, which may take the form of, for example, a differentiator circuit or a diode capacitor circuit. Preferably the circuit which defines a time window, for example, the aforementioned integrator together with a comparator to determine when the integrator once again reaches its reset value, is arranged so that the window is "opened" just before when the knee point is expected. This can be arranged, for example, by comparing the output of the integrator to its reset value, say zero, modified by a small offset.

Broadly, we have described a method and system for identifying the knee point by fitting a tangent to a portion of the power transformer voltage waveform, and sampling the VAUX at the knee point to determine the SMPS output voltage. In preferred embodiments this technique is implemented using a decaying peak detector, providing a timing signal indicating detection of the knee point. Sample/hold and error amplifier circuits may be employed to achieve output voltage regulation.

The techniques we have described provide a low cost method of accurately estimating the output voltage of a switched-mode power supply which achieves better output regulation, reduced audio noise and lower implementation cost than other primary-side sensing techniques.

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No doubt many other effective alternatives will occur to the skilled person. It will be understood that the invention is not limited to the described embodiments and encompasses modifications apparent to those skilled in the art lying within the spirit and scope of the claims appended hereto.

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CLAIMS:

1.   A system for sensing an output voltage of a switch mode power supply (SMPS), the SMPS including a switched magnetic energy storage device for conveying power from an input to an output of said SMPS, said magnetic device having at least one winding, the system comprising;

        an input to receive a sensing signal from said at least one winding of said magnetic device, said sensing signal having a waveform with a first, decaying portion during which power is supplied by said magnetic device to said SMPS output and a second, portion during which substantially no power is supplied by said magnetic device to said SMPS output;

        a signal follower coupled to said input to generate a decay signal approximating said decaying portion of said sensing signal waveform;

        a comparator to compare said decay signal with said sensing signal waveform to identify when said sensing signal waveform decays faster than said decay signal; and

        a sampler to sample said sensing signal responsive to said comparator to provide an output signal sensing said output voltage of said SMPS.

2.   A system as claimed in claim 1 further comprising an enable input to receive an enable signal, to disable the operation of said sampler during said second portion of said sensing signal.

3.   A system as claimed in claim 2 wherein said signal follower has a reset input coupled to said enable input to reset said decay signal responsive to said enable signal.

4.   A system as claimed in claim 1, 2 or 3 wherein said signal follower comprises a decaying peak detector to detect and hold with a decaying characteristic peaks of said sensing signal, said decaying peak detector having an output to provide said decay signal.

5.   A system as claimed in claim 4 wherein said decaying peak detector comprises a rectifier coupled to a capacitor and a discharge circuit coupled across said capacitor, and wherein said decaying peak detector output is provided from said capacitor.

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6.   A system as claimed in any preceding claim wherein said sampler comprises a sample-hold circuit coupled to said comparator to sample and hold said sensing signal when said sensing signal waveform decays faster than said decay signal to provide said output signal.

7.   A system as claimed in any one of claims 1 to 5 wherein said sampler comprises an integrator to sample said sensing signal by integrating said sensing signal waveform from when said sensing signal waveform decays faster than said decay signal to a later point on said sensing signal waveform.

8.   A system as claimed in any one of claims 1 to 7 for controlling said SMPS to operate in a discontinuous or critical conduction mode, wherein said second portion of said sensing signal waveform comprises an oscillatory portion of said waveform.

9.   A system as claimed in any one of the claims 1 to 7 for controlling said SMPS to operate in a continuous conduction mode, wherein said second portion of said sensing signal waveform comprises a portion of said waveform during which input power is switched to said magnetic energy storage device.

10.   An SMPS controller including the sensing system of any preceding claim and a comparator to compare said output signal with a reference to provide a control output for controlling an SMPS responsive to said comparison.

11.   An SMPS controller as claimed in claim 10 further comprising a timing signal generator to generate said enable signal.

12.   An SMPS controller as claimed in claim 11 wherein said timing signal generator is responsive to said sensing signal to detect a negative going zero-crossing of said sensing signal and to control said enable signal to disable operation of said sampler responsive to said detection.

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13.   An SMPS controller for controlling the output of an SMPS, the SMPS including a switched magnetic energy storage device for conveying power from an input to an output of said SMPS, said magnetic device having at least one winding, the controller comprising:

        a sense input to receive a sense signal waveform from said magnetic device;

        a decaying peak detector coupled to said sense input to detect when said sense signal waveform has a falling slope of greater than a threshold value and to generate a first timing signal:

        an output to provide an SMPS control signal responsive to a value of said sense signal waveform at a time indicated by said first timing signal.

14.   An SMPS controller as claimed in claim 13 further comprising:

        a timing signal input to receive a second timing signal indicating a time when substantially no power is being supplied by said SMPS; and

        wherein said SMPS control signal output is responsive to said second timing signal such that said control signal is substantially non-responsive to a value of said sense signal waveform at a time indicated by said first timing signal when said second timing signal indicates that substantially no power is being supplied by said SMPS.

15.   An SMPS controller as claimed in claim 13 or 14 further comprising a sample-hold module to sample and hold said sense signal waveform responsive to said first timing signal and having an output for providing said SMPS control signal.

16.   An SMPS controller as claimed in claim 15 further comprising a reference level input to receive an output voltage reference level signal, and an error detector coupled to said sample-hold module output and to said reference level input and having an output coupled to said SMPS controller output to provide said SMPS control signal responsive to a difference between said sampled sense signal waveform and said reference level signal.

17.   An SMPS controller as claimed in any one of claims 13 to 16 wherein said decaying peak detector comprises a peak detector coupled to said sense input and including a signal level memory element to store a peak level of said sense signal

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waveform and a decay element coupled to said memory element to reduce said stored peak level over time.

18.   An SMPS controller as claimed in claim 17 wherein said signal level memory element comprises a capacitor, and wherein said decay element comprises a current generator.

19.   An SMPS controller as claimed in claim 17 or 18 wherein said decaying peak detector further comprises a comparator to compare said stored peak level with said sense signal waveform to provide said first timing signal.

20.   A system or SMPS controller as claimed in any one of claims 1 to 19 wherein said magnetic device has at least two windings, including an auxiliary winding, and wherein said sensing signal is from said auxiliary winding.

21.   An SMPS including an SMPS controller as claimed in any one of claims 10 to 20.

22.   A method of sensing an output voltage of a switch mode power supply (SMPS), the SMPS including a switched magnetic energy storage device for conveying power from an input to an output of said SMPS, said magnetic device having at least one winding, the method comprising:

    inputting a sensing signal from said at least one winding of said magnetic device, said sensing signal having a waveform with a first, decaying portion during which power is supplied by said magnetic device to said SMPS output and a second portion during which substantially no power is supplied by said magnetic device to said SMPS output;

    identifying a knee point on said sensing signal waveform between said decaying portion and said second portion of said waveform; and

    using a value of said sensing signal at said knee point to sense said SMPS output voltage; and

    wherein said identifying of said knee point comprises fitting an approximate tangent to said decaying portion of said sensing signal waveform; and

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identifying departure of said sensing signal waveform from said approximate tangent to identify said knee point.

23.   A method as claimed in claim 22 wherein said tangent fitting comprises detecting one or more peaks of said sensing signal waveform, storing a peak level response to said detecting, and decaying said stored peak level to generate a tangent approximating signal.

24.   A method as claimed in claim 23 wherein said departure identifying comprises comparing said tangent approximating signal and said sensing signal waveform to identify a time when said sensing signal waveform departs from said tangent approximating signal to identify said knee point.

25.   A method as claimed in claim 24 further comprising sampling said sensing signal at said time when said sensing signal waveform departs from said tangent approximating signal to provide said value of said sensing signal at said knee point.

26.   A method as claimed in claim 25 wherein said sampling comprises integrating said sensing signal waveform from said knee point.

27.   A method as claimed in claim 25 or 26 wherein said departure identifying identifies a plurality of said times of departure of said sensing signal waveform from said tangent approximating signal, the method further comprising identifying a time when substantially no power is supplied by said magnetic device to said SMPS output and using a most recent said sample of said sensing signal prior to said identified time to provide said value of said sensing signal at said knee point.

28.   A method as claimed in claim 27 wherein said identifying of a time when substantially no power is supplied by said magnetic device to said SMPS output comprises identifying a crossing through a reference level of said second portion of said sensing signal waveform.

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29.   A method as claimed in claim 27 wherein said identifying of a time when substantially no power is supplied by said magnetic device to said SMPS output comprises identifying a crossing, through a reference level, of a time integral of said sensing signal waveform, said time integral being from a point of known substantially zero energy storage in said magnetic device.

30.   A method as claimed in claim 27 wherein said identifying of time when substantially no power is supplied by said magnetic device to said SMPS output comprises identifying a time with a fixed time delay from a crossing through a reference level of said sensing signal waveform.

31.   A method of sensing an output voltage of a switch mode power supply (SMPS), the SMPS including a switched magnetic energy storage device for conveying power from an input to an output of said SMPS, said magnetic device having at least one winding, the method comprising:

        inputting a sensing signal from said at least one winding of said magnetic device, said sensing signal having a waveform with a first, decaying portion during which power is supplied by said magnetic device to said SMPS output and a second portion during which substantially no power is supplied by said magnetic device to said SMPS output;

        identifying a knee point on said sensing signal waveform between said decaying portion and said second portion of said waveform; and

        using a value of said sensing signal at said knee point to sense said SMPS output voltage; and

        wherein said identifying of said knee point comprises detecting a point of greater than a threshold negative slope in said sensing signal waveform.

32.   A method as claimed in claim 31 wherein said knee point identifying further comprises selecting a portion of said sensing signal waveform for said detecting, to exclude at least a part of said second portion of said waveform.

33.   A method as claimed in claim 31 or 32 wherein said detecting comprises detecting a plurality of said points of greater than said threshold negative slope and

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selecting a said point immediately prior to said second portion of said waveform to identify said knee point.

34.   A method as claimed in any one of claims 22 to 33 further comprising regulating said output voltage of said SMPS responsive to said SMPS output voltage sensing.

35.   A method as claimed in any one of claims 22 to 34 wherein said magnetic device comprises a transformer, and wherein said inputting of said sensing signal waveform comprises inputting said sensing signal from an auxiliary winding of said transformer.

36.   A system for sensing an output voltage of an SMPS, the SMPS including a switched magnetic energy storage device for conveying power from an input to an output of said SMPS, said magnetic device having at least one winding, the system comprising:

        means for inputting a sensing signal from said at least one winding of said magnetic device, said sensing signal having a waveform with a first, decaying portion during which power is supplied by said magnetic device to said SMPS output and a second portion during which substantially no power is supplied by said magnetic device to said SMPS output;

        means for identifying a knee point on said sensing signal waveform between said decaying portion and said second portion of said waveform; and

        means for using a value of said sensing signal at said knee point to sense said SMPS output voltage; and

        wherein said means for said identifying of said knee point comprises:

        means for fitting an approximate tangent to said decaying portion of said sensing signal waveform; and

        means for identifying departure of said sensing signal waveform from said approximate tangent to identify said knee point.

37.   A system for sensing an output voltage of an SMPS, the SMPS including a switched magnetic energy storage device for conveying power from an input to an

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output of said SMPS, said magnetic device having at least one winding, the system comprising:

means for inputting a sensing signal from said at least one winding of said magnetic device, said sensing signal having a waveform with a first, decaying portion during which power is supplied by said magnetic device to said SMPS output and a second portion during which substantially no power is supplied by said magnetic device to said SMPS output;

means for identifying a knee point on said sensing signal waveform between said decaying portion and said second portion of said waveform; and

means for using a value of said sensing signal at said knee point to sense said SMPS output voltage; and

wherein said means for said identifying of said knee point comprises:

means for detecting a point of greater than a threshold negative slope in said sensing signal waveform.

38.   A system or SMPS controller as claimed in any one of claims 1 to 19 wherein said magnetic device comprises a transformer and wherein said sensing signal is from a primary winding of said transformer or a method as claimed in any one of claims 22 to 34 wherein said magnetic device comprises a transformer and wherein said inputting of said sensing signal waveform comprises inputting said sensing signal from a primary winding of said transformer.
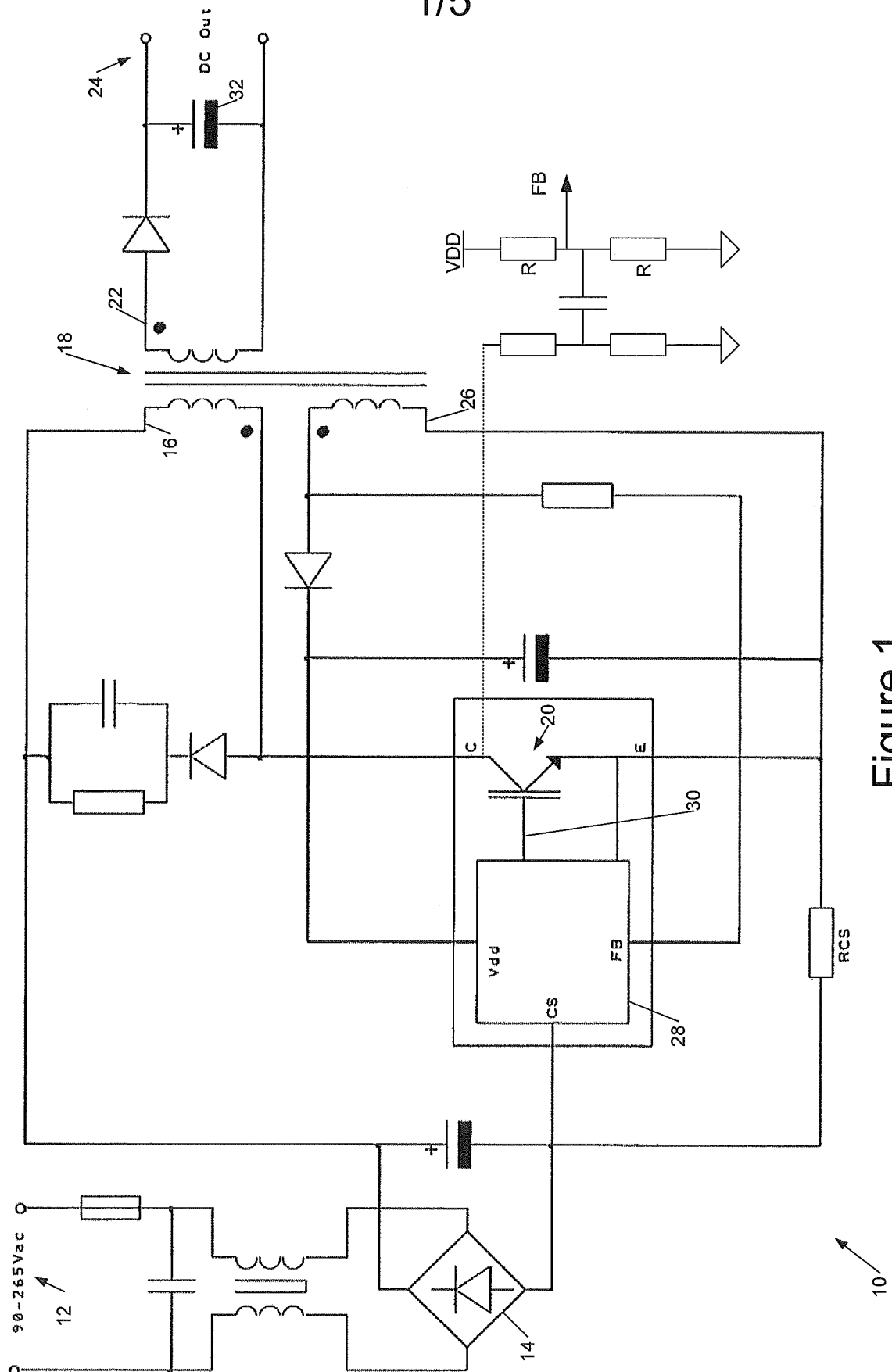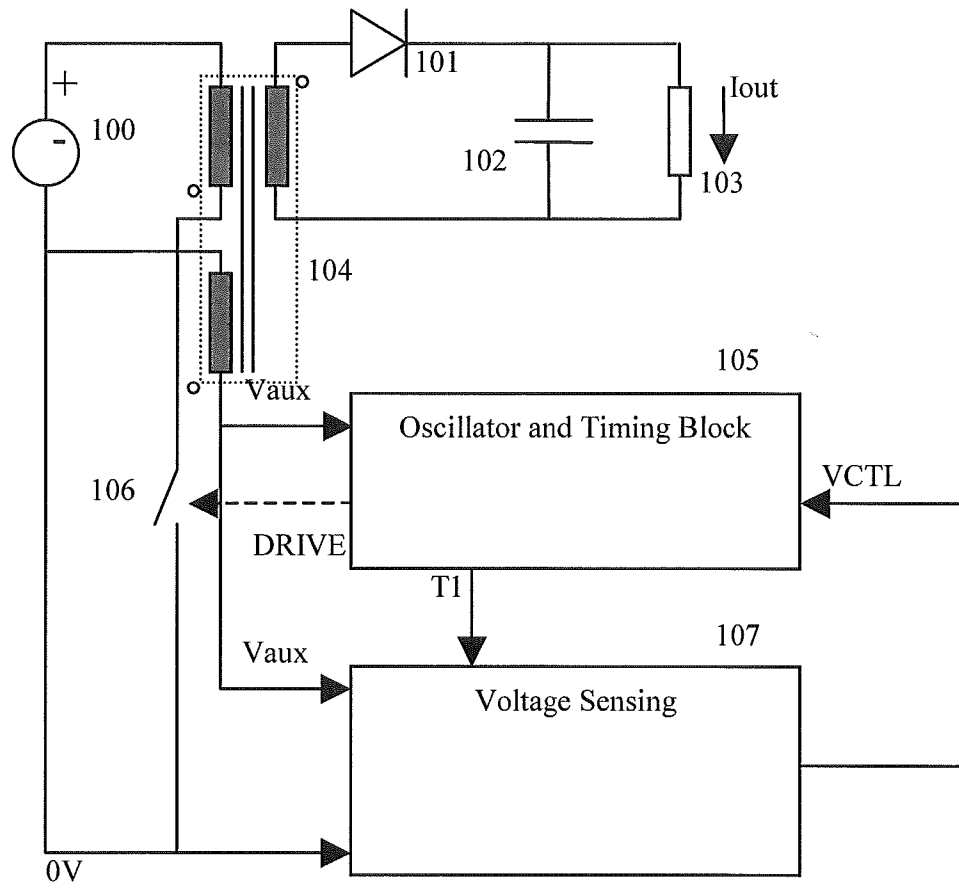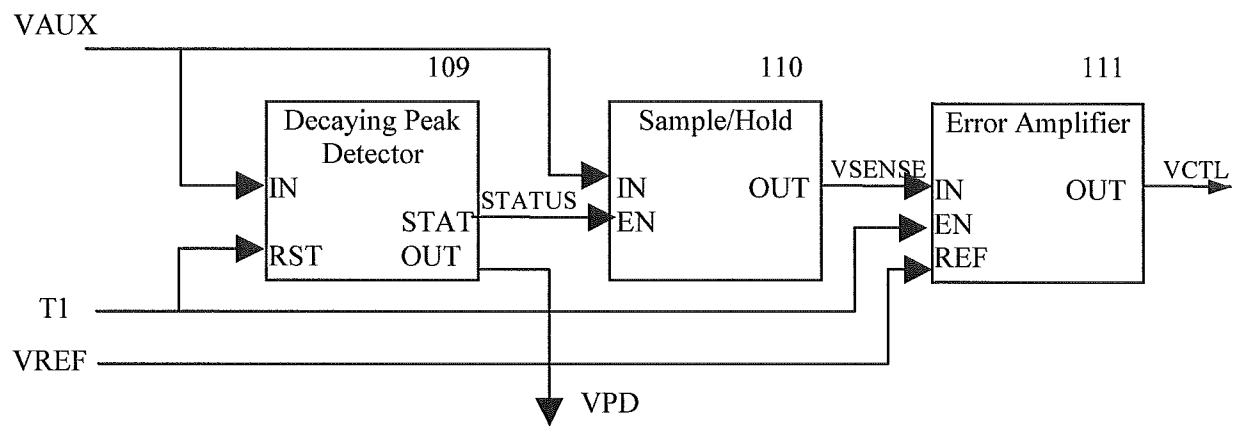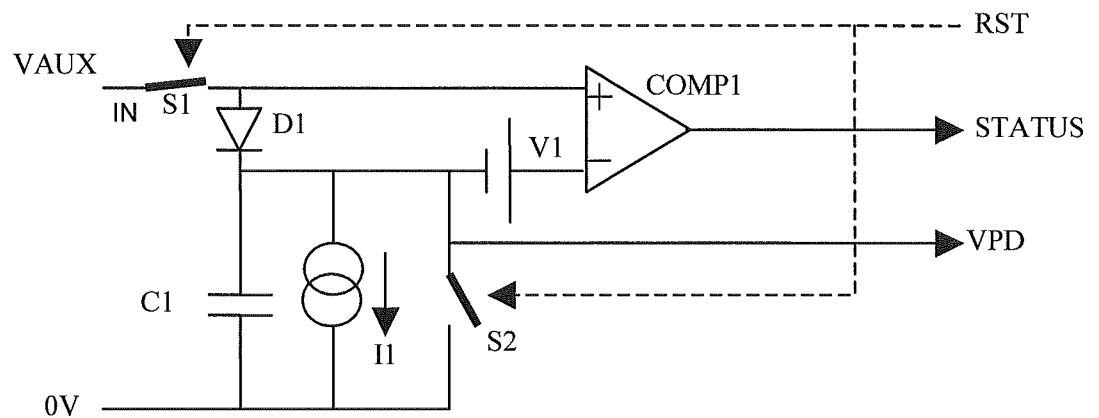
Figure 1

Figure 2

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Figure 3

Figure 4

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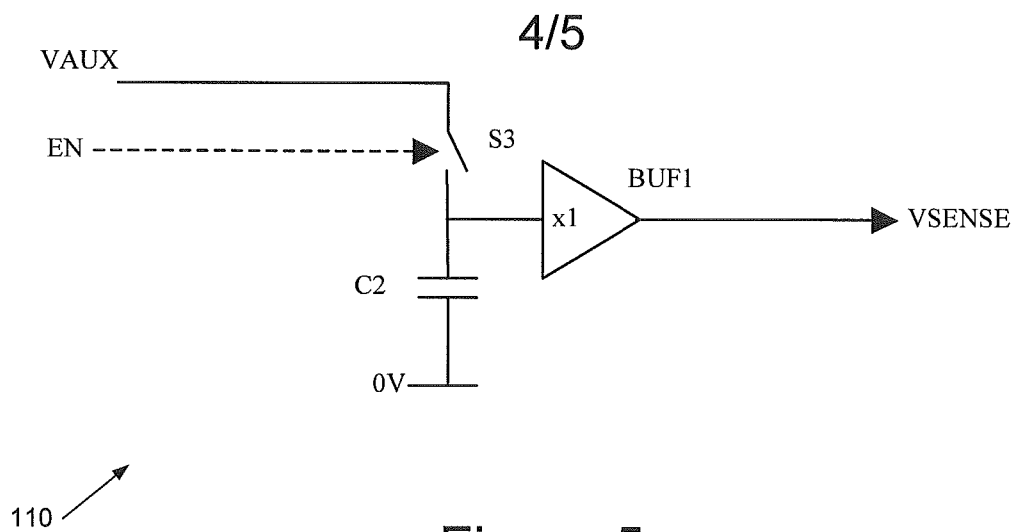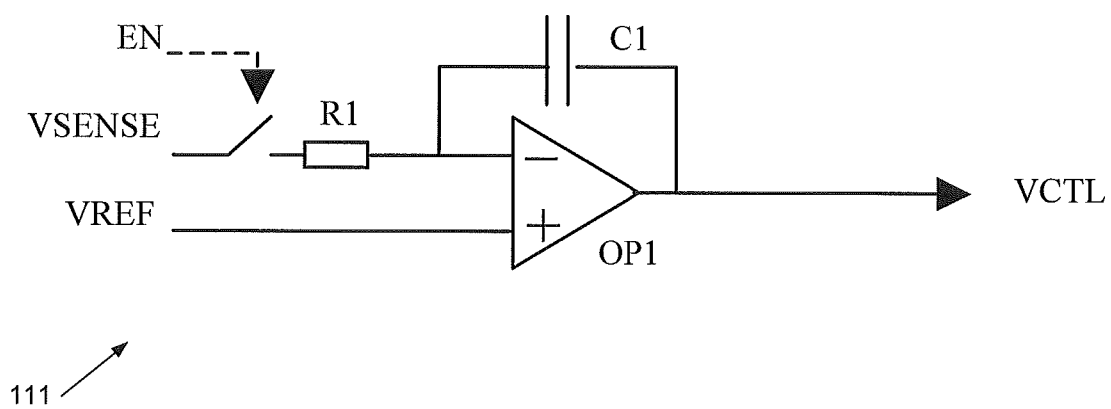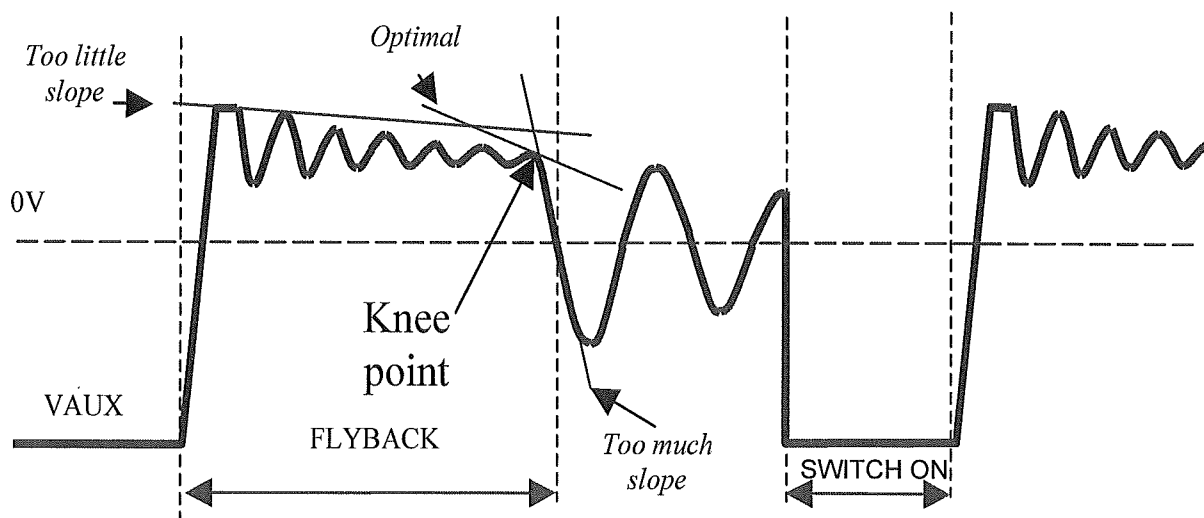

Figure 5

Figure 6

Figure 7

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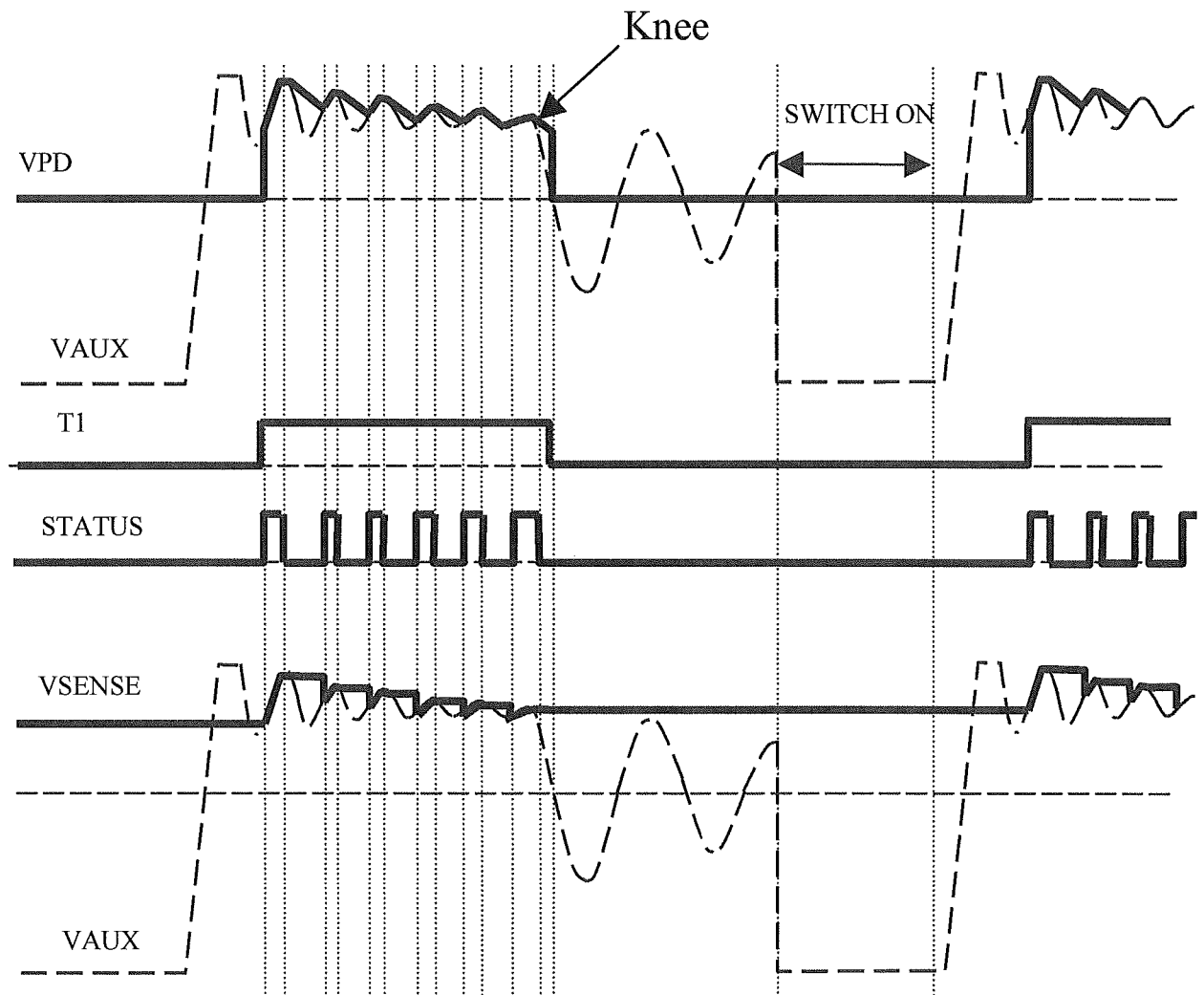
Figure 8

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02M3/335

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)
H02M

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2006/050539 A1 (YANG TA-YUNG [US] ET AL YANG TA-YUNG [US] ET AL) 9 March 2006 (2006-03-09) cited in the application abstract paragraphs [0034], [0053] claim 10 figures 1,2,6	1-38
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| X | Further documents are listed in the continuation of Box C.

| X | See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 July 2007	06/08/2007

| Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016 | Authorized officer Roider, Anton |

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International application No
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A	US 2002/015315 A1 (TELEFUS MARK D [US]) 7 February 2002 (2002-02-07) cited in the application abstract figures 3,10	1-38
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Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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C(Continuation).	DOCUMENTS CONSIDERED TO BE RELEVANT	
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 6 301 135 B1 (MAMMANO ROBERT A [US] ET AL) 9 October 2001 (2001-10-09) cited in the application abstract figure 1	1-38
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 333 624 B1 (BALL ALAN [US] ET AL) 25 December 2001 (2001-12-25) cited in the application abstract figure 2 –––––	1-38

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