

A DC Voltage Supply Circuit

The present invention relates to a DC supply circuit, particularly but not exclusively for use in mains powered equipment which detects the magnitude of the mains voltage applied and accordingly adjusts the operation of associated rectifier circuitry.

There exists, throughout the world, a wide variety of mains AC voltages. Broadly, there are two groups: those of the low voltage range (88-132Vrms) and those of the high voltage range (176-264Vrms). It is desirable to design electrically powered equipment which can be used throughout the world, thereby to simplify design and production and to allow equipment to be portable between countries other than where originally purchased. This requires that the equipment must be adaptable for use on both voltage ranges.

The simplest way of achieving this has been to associate a manually operated doubler/bridge switch with the equipment. The operator will set the switch to the correct position before applying the mains voltage to the equipment.

Figures 1A and 1B illustrate a manually operated doubler/bridge switch. Four diodes D_1 - D_4 are connected together as bridge rectifier. An AC input voltage V_{LN} is applied between nodes 2, 4, where node 2 is connected to the anode of D_1 and the cathode of D_3 , and node 4 is connected to the anode of D_3 and the cathode of D_1 . Two capacitors C_1 , C_2 , preferably of equal value, are connected in series between nodes 6, 8, being the DC output nodes of the bridge rectifier. A load L is connected between nodes 6, 8 and is supplied with the DC output. A switch T is connected between node 4 and node 10, being the node between the two capacitors. When the manual switch T is open, as shown in figure 1A, diodes D_1 - D_4 form a conventional bridge rectifier with capacitors C_1 , C_2 to smooth the DC output generated. This is the bridge rectification mode. When the switch T is closed, as shown by figure 1B, diodes D_1 , D_2 and capacitors C_1 , C_2 operate as a combined voltage doubler and rectifier circuit of the known type. Diodes D_3 , D_4 are superfluous in this mode. This is the voltage doubling rectification mode.

One major drawback of the manually operated doubler/bridge switch is

that forgetting to check the position or choosing the wrong position of the switch would cause damage to the equipment, otherwise the equipment will have to be predesigned to prevent such damage, incurring extra cost.

An automatic doubler/bridge switch circuit is also known, which automatically doubles and rectifies a low range AC input voltage and which merely rectifies a high range AC input voltage. Sensing of the voltage level of the mains may be done by detecting peak voltage values of the AC waveform and using voltage comparators, or by sensing the magnitude of a DC rectified input voltage. Such circuits are available in either integrated circuit or discrete component form.

Such an integrated circuit automatic doubler/bridge switch is described in US patent N° 5,162,984, of SGS-Thomson Microelectronics SA. A triac or equivalent thereof is used in place of the manual switch T.

A triac acts to conduct in either direction after the application of a negative (active low) pulse to its gate terminal, until the voltage across its two main terminals falls below a minimum value. By applying a gate pulse soon after every mains zero crossing point, the triac approximates to a short circuit. The introduction of such a short circuit provides the changeover from the bridge rectification mode shown in figure 1A to the voltage doubling rectification mode shown in figure 1B.

An alternating voltage is a voltage which undergoes successive upper and lower excursions, respectively more and less positive than a baseline voltage, such baseline voltage being the time average of the alternating voltage. For a mains alternating voltage, the baseline voltage is at the ground (zero volts) level.

The automatic voltage sensitive switch circuit described in the patent is a circuit containing several voltage comparators: these are used to detect peak voltage values to indicate a mains input AC voltage of the higher range, and to detect baseline crossing points to give timing information for triac gate pulses. Voltage reference sources are also built into the circuit to set the voltage reference points of the comparators. Means may be provided for generating many triac gate pulses per half-cycle of AC mains, to ensure efficient triggering in the presence of noise or disturbance on the AC lines. Filtering circuits may be included to remove such noise or disturbance from the voltage used for peak voltage detection.

Such integrated circuits are small and reliable. The cost of an automatic

voltage sensitive switch circuit is reduced by reducing the number of components required, external to the integrated circuit.

Known automatic voltage sensitive switches employ a "single cycle" sensing mechanism, i.e. peak voltage level sensing is carried out on either only the upper or only the lower excursion of the mains voltage, linear extrapolation techniques being used to derive data for the other excursion.

This limitation is due to the fact that filtering, baseline crossing detection and peak voltage level sensing may only be carried out on a scaled representation of AC input voltages falling within a range limited by the two DC supply voltage levels of the control circuit of the automatic voltage sensitive switch. These are typically 0V and 9V. The AC input voltage is scaled down for input to the control circuit, but as it is centred on 0V, the mains baseline, only one of the upper and lower excursions of the scaled AC voltage will fall within the allowed range for peak voltage level sensing.

Referring to figure 2, an embodiment of such an automatic voltage sensitive switch is shown. A doubler/bridge circuit 20 includes a triac T switching element; nodes 2, 4 are connected to the live L and neutral N lines of the AC mains, and receive the AC input voltage V_{LN} . A diode D_3 , a resistor R_4 and a capacitor C are respectively connected in series between the live line L and the neutral line N. Two resistors R_1 , R_2 are connected in series between the live line L and the node 22 between the capacitor C and the resistor R_4 . The voltage between the neutral line N and node 22 is the voltage V_C across the capacitor C. The automatic voltage sensitive switch control circuit 24 receives a first input voltage V_{ss} from the node 22 and a second input voltage V_1 from the neutral line N and a third, 'composite', input voltage, V_M from the node 26 between resistors R_1 , R_2 , and supplies an output voltage V_{GT} through a resistor R_g to the gate G of the triac T.

Diode D_3 , resistor R_4 and capacitor C form a half-wave rectifier and smoothing circuit and provide a DC supply voltage V_C to the automatic voltage sensitive switch control circuit 24. V_{ss} is taken as a ground voltage for the circuit. It is at a voltage V_C less than the voltage of the neutral line N. (For example, 9V less as fixed by a regulator within the control circuit). The AC input voltage V_{LN} is applied to the potential divider comprising resistors R_1 , R_2 . The composite

voltage V_M received by the control circuit 24 is a scaled down AC input voltage, displaced by a small DC offset, given by:

$$V_{LN} = V_2 - V_4,$$

where V_2 and V_4 denote the instantaneous voltages at nodes 2 and 4, respectively.

$$\begin{aligned} V_{LN} &= V_2 - V_{ss} - V_4 + V_{ss} \\ &= V_2 - V_{ss} - (V_4 - V_{ss}) \\ &= V_2 - V_{ss} - V_C \end{aligned}$$

$$V_{LN} + V_C = V_2 - V_{ss} \quad [1]$$

Also,

$$V_M = \frac{(V_2 - V_{ss}) \times R_2}{R_1 + R_2}.$$

Using equation [1],

$$V_M = \frac{R_2(V_{LN} + V_C)}{R_1 + R_2}$$

Hence, both the scaled AC input voltage and the DC bias depend on the values of R_1 and R_2 . Their values are chosen such that, for DC supplies of 0V and 9V to the control circuit, the peak voltage of V_M will be less than 9V in the presence of the highest possible instantaneous line voltage. For example, if $R_1 = 1\text{M}\Omega$ and $R_2 = 18\text{k}\Omega$, $R_2/(R_1 + R_2) = 0.0177$, and the peak voltage for a 264Vrms AC input would be $264 \times \sqrt{2} \times 0.0177 = 6.60\text{V}$. The input voltage to the control circuit V_M would be an AC voltage of 6.60V peak, almost centred on 0V, but offset by $0.0177 \times V_C = 0.16\text{V}$. In this way, only the positive peak voltages of V_M will fall within the allowed range of input voltages, fixed at $V_4 + 0.6\text{V}$ to $V_{ss} - 0.6\text{V}$ by input protection devices in the control circuit 24. The DC offset of 0.16V means that the baseline of the composite voltage V_M is at 0.16V, and baseline crossing points may be detected, including hysteresis, by detecting when V_M crosses 0.05V and 0.25V, for example.

Figures 3 and 4 show example input and output signals for the known automatic voltage switches carrying out comparison operations on the input voltage described. A scaled AC input voltage V_{LN} is clipped by the input protection devices to remain within the range R , to obtain a measurable composite voltage V_M . A pulse PD is produced when V_M exceeds a certain threshold voltage V_{TP} . Pulses CS

represent the times during which $V_M > 0V$. The inverse of this signal is produced within the control circuit 24. A short pulse is produced at each rising edge of CS and its inverse, which are added to form the signal ZC, which indicates the baseline crossing points of V_M , and hence the mains zero crossing points.

Peak detection pulses PD are produced at the peak of every upper excursion for a high range AC input voltage, using a comparator whose switching threshold is set to detect a voltage V_{TP} in excess of the peak voltage of the highest scaled AC voltage of the lower range. For example, V_{TP} may correspond to an instantaneous AC input voltage of 220V, the peak value of a 156Vrms AC input voltage. The threshold voltage must be carefully chosen, as AC mains voltages are subject to variation from time to time, resulting in the fact that the separation between a low range AC input voltage and a high range input voltage may be as small as 30Vrms (140Vrms to 170Vrms).

Such peak detection pulses PD, disable the generation of triac pulses V_{GT} .

As shown in figure 4, no peak detection pulses PD are produced for low voltage AC input as the composite voltage V_M never passes the V_{TP} threshold. As described above, a comparator whose switching threshold is the baseline voltage level produces the comparison signal CS. Its inverse is also produced, and short pulses are generated at each rising edge of both CS and its inverse. The sum of these short pulses is the mains zero crossing indication signal ZC.

Internal logic then uses pulses PD to extrapolate corresponding data for the other excursion, and to generate triac gate firing pulses V_{GT} , a certain delay after each mains zero crossing point.

Voltage level detection is limited to one excursion only per cycle due to input protection devices, which limit the composite voltage V_M to the allowed range R in figures 3 and 4, being 0.6V either side of the supply voltages. This eliminates any possibility of performing measurements on the other excursion per cycle of the waveform, in this example, the negative excursion.

Circuitry built into the control circuit 24 verifies a change in the apparent voltage range for at least two mains cycles before changing from bridge rectifier mode to voltage doubling rectification mode, so as to avoid the possibility of

doubling a high range AC input voltage after a brief drop in AC input voltage.

A temporal filter is included within the control circuit to reduce the effects of glitches, sags, spikes and voltage surges. This is only active on input voltages which lie within the range R.

The limitation which is imposed on this circuit, in that it can perform filtering and voltage level sensing on only one half of the AC mains input signal results in several drawbacks.

Due to the voltage amplitude sensing on one half of the waveform only, there is the possibility of doubling a whole cycle of high voltage mains which may appear during an unsensed excursion of the AC input. Turn-off to non-doubling mode will not occur until the next baseline crossing after sensing has been performed on a sensed excursion of the input AC cycle. This could lead to damage to the bulk smoothing capacitors C_1 , C_2 and the load L, due to one whole mains cycle of voltage far exceeding the device ratings, e.g. 480V DC, being applied, as the DC output voltage will become double the AC input voltage for one whole cycle.

Furthermore, the filtering described is not effective on half the wave, leaving the control circuit vulnerable to damage caused by such transients on the unsensed portion of the AC input wave. To date, these deficiencies have been tolerated.

Automatic voltage switches using the detection of a DC rectified version of the AC input voltage are also known, for example as described in US patent N° 4,665,323, but these have the disadvantage of requiring additional high voltage diodes, smoothing capacitors and power resistors, which cannot be included in an integrated circuit, and therefore leading to a complex and expensive solution.

Automatic voltage switching circuits also exist in discrete form, whereby the circuit contains a voltage comparator, with one input referenced to a zener diode, to detect rectified or scaled AC voltages above a certain upper or lower threshold, as defined by the zener diode, and circuitry to provide triac gate firing pulses when required.

The object of the current invention is to provide a DC voltage supply

circuit for rectifying an alternating voltage, using a minimum of discrete components, whilst improving sensing accuracy and reducing the circuit cost and complexity.

The invention provides voltage level sensing during both positive and negative half cycles of the AC mains. This is achieved by adjusting the DC offset of the composite voltage, in order to bring the total composite voltage within the limits defined by the DC supply voltages, for the whole cycle of mains AC, and allow voltage level detection and filtering of the waveform over its whole cycle.

According to one aspect of the present invention, a DC voltage supply circuit is provided for rectifying an alternating voltage and supplying a DC output voltage at a substantially constant value. Such a voltage supply circuit includes: rectification circuitry for rectifying the alternating voltage; a voltage detection circuit for detecting, within upper and lower limits, peak values of said excursions for controlling said rectification circuitry; and a voltage shift circuit. The voltage shift circuit is arranged to receive the alternating voltage as an input, and connected to supply a composite voltage to the voltage detection circuit. It scales the input alternating voltage and shifts its baseline by a preselected DC bias, in order that the excursions fall within the upper and lower limits so that the voltage detection circuit is operable to detect peak values of both upper and lower excursions. If the input alternating voltage has a baseline other than at 0V, the baseline voltage will also be scaled and included in the scaled alternating input voltage. The composite voltage is the sum of the DC bias voltage and the scaled alternating input voltage.

Such a DC voltage supply circuit may be operable within at least two distinct ranges of values of the alternating voltage. The output of the voltage detection circuit indicates the range containing the applied alternating voltage. The rectification circuitry has a number of modes equal to the number of distinct ranges of values of the alternating voltage, and the mode of operation of the rectification circuitry is selected according to the range indicated.

Baseline crossing detection circuitry may be included to detect the times at which the input alternating voltage crosses its baseline; and the rectification circuit includes a switch, e.g. a triac, for selecting the mode of operation. The baseline detection circuitry is then used to generate control signals to the switch.

These control signals are pulses when the switch is a triac. The rectification circuitry may be a doubler/bridge rectifier, with two modes of operation.

The required preselected DC bias may be derived from DC supply voltages to the voltage detection circuit, while the scaled alternating input voltage may be provided by a resistive or capacitive divider network placed between the alternating input voltage and one of the voltage detection circuit supply voltages. The DC bias is then selected by controlling the DC current through one of the elements of the resistive divider.

The voltage detection circuit preferably contains a plurality of voltage comparators, receiving a plurality of voltage references each corresponding to a threshold to be detected. In one embodiment of the invention, the reference voltages are each defined as a voltage which tracks the baseline of the composite voltage, being a variable voltage, the reference voltage remaining at a fixed voltage therefrom independently of the variations in V_C . Accordingly, another aspect of the invention provides a voltage generation circuit including a reference voltage generator generating a reference voltage which is constant with respect to a ground voltage, a voltage multiplication circuit for multiplying the reference voltage by a certain multiple to provide the fixed voltage, and an offset circuit for offsetting the fixed voltage by the varying voltage.

Such a circuit may include a first operational amplifier connected so as to receive both the reference voltage and a DC bias, and producing an output voltage equal to the preselected DC bias minus a predetermined multiple of the reference voltage V_{BG} . A second operational amplifier has one input connected via a first resistance to the output of the first amplifier and another input connected to receive the preselected DC bias. The second amplifier has an output connected via a second resistance to its said one input. The first and second resistances are preferably equal. Thus, the second operational amplifier produces an output voltage equal to the preselected DC bias plus the predetermined multiple of the reference voltage V_{BG} . The first and second resistances may be provided by a resistive divider network including a set of nodes connected between the output of the first amplifier and the output of the second amplifier, whereby a different required voltage reference is available at each node.

Alternatively, and according to another aspect of the invention, a reference voltage generation circuit may be provided which includes a fixed reference current generator generating identical currents through two series portions of one circuit branch, at least one portion including a resistive element, a node between the two series portions being connected to receive the varying voltage. The varying voltage may be a fraction of the supply voltage to the circuit. The circuit branch includes a first transistor of a first channel type, a resistive element and a first transistor of a second channel type respectively connected between the supply voltage to the circuit and the ground voltage.

A detailed description of certain particular embodiments of the present invention will hereinafter be described, by way of examples, with reference to the accompanying diagrams.

Figure 1A shows a circuit diagram of a manual doubler/bridge circuit in bridge rectification mode;

Figure 1B shows a circuit diagram of the manual doubler/bridge circuit in voltage doubling rectification mode;

Figure 2 shows a circuit diagram of an automatic voltage sensitive switch circuit of the prior art;

Figure 3 shows input and output signals of the circuit of figure 2 when subjected to a high range AC input voltage;

Figure 4 shows input and output signals of the circuit of figure 2 when subjected to a low range AC input voltage;

Figure 5 shows input and output signals of a circuit according to an embodiment of the present invention;

Figure 6 shows a circuit of an automatic voltage sensitive switch circuit according to an embodiment of the present invention;

Figure 7 shows a current loop diagram of part of the circuit of figure 6;

Figure 8 shows a circuit diagram of an automatic voltage sensitive switch circuit according to a second embodiment of the invention;

Figure 9 shows an effect of a drop in supply voltage on the detection of voltage levels;

Figure 10 shows another effect of a drop in supply voltage on the detection of voltage levels;

Figure 11 shows the desired effect of a drop in supply voltage on reference voltages used in the circuit of the invention;

Figure 12 shows a circuit for the generation of reference voltages;

Figure 13 shows another circuit for the generation of reference voltages;

Figure 13A shows further circuitry for the generation of reference voltages;

Figure 13B shows a preferred circuit for the generation of reference voltages, incorporating the circuitry of figures 13 and 13A;

Figure 14 shows a circuit diagram of an automatic voltage sensitive switch circuit according to a third embodiment of the invention; and

Figure 15 shows input and output signals of the circuit of figure 14.

Figure 5 illustrates the operation of the circuit of the invention. Two cases are illustrated: one for the case where a high range AC input voltage is applied, the second where a low range input voltage is applied. Scaled AC input voltages are shifted by a DC offset voltage V_{DC} , to produce composite voltages V_{MH} , V_{ML} . An upper threshold voltage V_{PH} and a lower threshold voltage V_{PL} are defined. The allowed range R of input voltages to the control circuit is shown. When a high voltage range composite voltage V_{MH} is applied to the circuit, positive peak detection pulses $P1$ are produced when the composite voltage V_{MH} exceeds the upper threshold V_{PH} , and negative peak detection pulses $P2$ are produced when the composite voltage V_{MH} falls below the lower threshold voltage V_{PL} , the thresholds being fixed within the circuitry using an internal voltage reference. Mains zero crossing indication signal ZC produces a pulse every time the composite voltage V_{MH} , V_{ML} crosses the baseline voltage of V_M , whatever the level of the AC input, using comparators set to detect the crossing of the baseline voltage for the composite voltage V_{ML} , V_{MH} . When the AC input voltage has a baseline at 0V, the baseline voltage of V_M is equal to the DC offset voltage V_{DC} . In this way, timing and voltage level information may be gained for the whole AC cycle. When peak detection pulses $P1$, $P2$ are produced, no triac gate pulses are produced and the triac gate voltage V_{GT} remains at the high (inactive) state. For a low range AC

input, no peak detection pulses are produced as the composite voltage V_{ML} crosses neither the upper nor the lower threshold voltages V_{PH} , V_{PL} ; active low triac gate pulses V_{GT} are produced, a certain time after each mains zero crossing indication pulse ZC . Hysteresis may be included for each peak or baseline crossing detection, to avoid noisy detection, and provide system level hysteresis for triac stability. This will require two thresholds for each detection.

The scaling ratio and the DC offset V_{DC} of the composite voltages, V_{MH} , V_{ML} are chosen such that even for the highest possible AC input, the composite voltage V_{MH} used by the control circuit lies within the allowed range R for its entire cycle. Peak detection can then be performed during both the positive and negative half cycles of the AC input.

The required DC offset voltage V_{DC} may be obtained by passing a DC current of known value through a finite resistance also of known value, and summing the resulting potential with a representation of the AC mains input voltage.

Figure 6 shows an automatic voltage switch control circuit according to the current invention. The circuit is similar to that of figure 2, and similar features have similar reference labels. A resistor R_3 is placed between the node 26 and the neutral AC input line N . The control circuit 30 includes functions additional to those included in the control circuit 24 of figure 2, to enable it to perform voltage level detection during both positive and negative excursions of the alternating input voltage V_{LN} .

The AC input voltage V_{LN} is scaled by the use of a resistive divider R_1 , R_2 . The resistor R_3 is included in the circuit to supply an additional DC current through a part R_2 of the resistive divider in order to increase the DC offset of the composite voltage V_M to the control circuit. Such DC current is conveniently supplied by the DC supply V_{ss} to the control circuit 30, in this case supplied from the AC input voltage by use of a simple half-wave rectifier D_5 and smoothing circuit C , R_4 .

The value of the resistor R_3 is preferably such as to achieve a DC bias voltage V_{DC} equal to the average of the supply voltages V_{ss} , V_1 of the control circuit 30.

Preferably, a DC offset of $V_C/2 = 4.5V$ is required for V_M , to place the

composite voltage V_M at the midpoint of the allowable range, with a 9V supply to circuit 30, provided that the alternating input voltage has a baseline of 0V. The DC offset is the value of V_M when the AC input voltage $V_{LN} = 0V$.

If, as discussed above, $R_1 = 1M\Omega$ and $R_2 = 18k\Omega$, a negligible amount of current is drained through R_1 ; R_2 and R_3 effectively form a DC voltage divider between the V_{ss} voltage and the neutral line voltage V_4 . We therefore require that:

$$V_C \times \frac{R_2}{R_2 + R_3} = \frac{V_C}{2}$$

or $R_3 = R_2$, giving $R_3 = 18k\Omega$.

Figure 7 shows a simplified current loop diagram of the resistive divider and DC biasing circuitry of the circuit of figure 6. A current I_1 flows from the AC input lines, represented by the voltage source V_{LN} , through the voltage source V_C (which represents the capacitor C), through the resistors R_2 and R_1 back to the AC lines. A current I_2 flows from the voltage source V_C through the resistors R_3 , R_2 back to the voltage source. A current I_3 flows from the voltage source, V_C , through the resistor R_2 and into the V_M input of the control circuit 30.

Applying Kirchoff's law to the current loops shown in the diagram, and ignoring the control circuit input bias current I_3 which is of very small magnitude,

$$V_M = R_2(I_1 - I_2) \quad \text{---[2]}$$

$$V_{LN} = V_C + (I_1 - I_2)R_2 + I_1R_1 \quad \text{---[3]}$$

$$V_C = I_2R_3 + (I_2 - I_1)R_2 \quad \text{---[4]}$$

from which it follows that:

$$V_{LN} - V_C = I_1(R_1 + R_2) + I_2(-R_2) \quad \text{---[5]}$$

$$V_C = I_1(-R_2) + I_2(R_2 + R_3) \quad \text{---[6]}$$

Substituting into equations [4] and [5] and using units of volts, $k\Omega$ and mA, for the known values of $V_C = 9V$, $R_2 = R_3 = 18k\Omega$, it follows that:

$$V_{LN} - 9V = I_1(1018) - 18I_2 \quad \text{---[7]}$$

$$9V = -18I_1 + 36I_2 \quad \text{---[8]}$$

Multiplying the terms of equation [7] by 2 and adding with equation [8], I_2 is

eliminated, with the result:

$$\begin{aligned} 2V_{LN} - 9 &= 2018 I_1; \\ I_1 &= (2V_{LN} - 9) / 2018 \end{aligned} \quad \text{---[9]}$$

To test the result, the peak voltages which appear at V_M are calculated, to make sure that they lie within the permitted range, being between 0 and 9V, referenced to V_{ss} .

Thus, for a $V_{LN} = 373V$, and according to equation [9],

$$I_1 = 0.366 \text{ mA};$$

substituting this into equation [8] gives

$$I_2 = 0.433 \text{ mA}.$$

From equation [2], it follows that

$$V_M = 1.213V,$$

thus above V_{ss} and within the permitted range.

Similar calculations for the most negative instantaneous input voltage, when $V_{LN} = -373V$ gives

$$V_M = 7.87V,$$

thus below the neutral line voltage, and within the permitted range.

This means that the AC voltage will now be centred on the middle of the allowed range, and all the whole cycle of the AC input will stay within the allowed range, with suitably chosen resistor values for R_1 , R_2 , R_3 . With the inclusion of the resistor R_3 , the scaling factor for the AC input voltage is:

$$\frac{R_2 \parallel R_3}{R_1 + R_2 \parallel R_3}$$

Figure 8 represents a second embodiment of the invention. The circuit is similar to the circuit of figure 6, and similar features have similar reference figures.

The alternating input voltage V_{LN} is scaled by the use of a capacitive divider C_3 , C_1 . Capacitor C_3 is chosen to have an impedance value much smaller than that of C_1 , to provide an AC component of composite voltage V_M which is less than 9V peak to peak. For example, by choosing $C_1 = 0.012$, C_3 , the impedance of C_3 will be 0.012 times that of C_1 , and the voltage across C_3 with a peak voltage of 264Vrms mains voltage will be $264 \times \sqrt{2} \times (0.012/1.012) = 4.4V$. Use of the

capacitive divider C_3 , C_4 removes any DC component from the input alternating voltage, which therefore may be considered as having a baseline voltage of 0V. A resistive divider R_5 , R_6 is placed across the DC supply voltages V_4 , V_{ss} to the circuit, and provides a DC offset voltage of V_M . To supply an offset voltage equal to the average of the two supply voltages, the two resistors R_5 , R_6 must be of an equal value.

The composite voltage V_M supplied to the control circuit 30 is then:

$$V_M = \frac{C_4 \cdot V_{LN}}{C_4 + C_3} + \frac{R_5 \cdot 9}{R_5 + R_6}$$

If the supply voltages to the control circuit are 0V (V_{ss}) and 9V (V_4), the AC input voltage must be scaled by C_3 , C_4 so that there is less than 9V peak to peak, and be displaced by a DC offset voltage by R_5 , R_6 so as to produce a composite voltage V_M whose most negative peak is greater than 0V, and the whose positive peak is less than 9V.

Similar calculations may be performed for any other type of automatic voltage switch contemplated for use.

In the two embodiments of the invention described, peak voltage levels and mains zero crossing points are detected by applying the composite voltage V_M to several voltage comparators, each supplied with a voltage reference point representing a threshold for the detection of a peak voltage, or a baseline crossing point. The required reference voltages may be set by use of a bandgap voltage reference, suitably amplified, and referenced to a ground potential such as V_{ss} . The amplified output of the bandgap voltage reference may be divided by a fixed resistive divider to provide a set of several reference voltages. Input voltage requirements of the voltage comparators and amplifiers may limit the permitted range of values of the composite voltage V_M to between ($V_4 - 0.6V$) and ($V_{ss} + 0.6V$).

This method has the drawback that any variation in the voltage V_C across the capacitor C in figure 8. will be reflected in the magnitude of the composite voltage V_M , which includes a DC component V_{DC} , derived from V_C . Such variations in the voltage V_C may be caused by the discharge of capacitor C during mains

voltage irregularities, which lead to reduced charging of the capacitor C, as well as the possibility of repeated triac firing pulse generation, which will further drain the charge on capacitor C. Such mains voltage irregularities have a greater effect on the value of V_C than they do on the magnitude of the alternating component of V_M . If V_C is provided other than by the input alternating voltage, variations in current drains of other circuits connected to the same DC supply could also cause variations in V_C .

The reference voltages, however, being an amplified bandgap voltage, and referenced to a ground potential V_{ss} , are independent of any changes in the voltage V_C , and thus are unaffected by any variations in this voltage. This will upset the measurement of alternating voltage magnitude and zero crossing points.

Figure 9 illustrates the problem caused. The composite voltage V_M represents the voltage applied to the control circuit during a period of high range alternating input voltage. The composite voltage V_M has positive peaks at times t_{p1} , t_{p2} , t_{p3} and negative peaks at times t'_{p1} , t'_{p2} . Both upper and lower peak detection thresholds, V_{TH} , V_{TL} are included, with optional additional thresholds V'_{TH} , V'_{TL} for hysteresis. Crossing of these thresholds by the voltage V_M leads to the production of peak detection pulses P1, P2. The comparison signal CS changes state every time the composite voltage V_M crosses the baseline crossing detection thresholds V_{ZC} , V'_{ZC} .

A drop ΔV_C in voltage V_C occurs at time t_A . As the composite voltage V_M monitored by the automatic voltage sensitive switch control circuit 30 includes a DC offset voltage V_{DC} equal to $\frac{1}{2}V_C$, V_M drops by $\frac{1}{2}\Delta V_C$. Due to this, the positive peak voltage occurring at time t_{p2} does not cross V_{TH} , the positive peak detection threshold. No peak detection pulse is therefore present on signal P1; a peak of high voltage input goes undetected. When a negative peak voltage occurs at time t'_{p2} , the thresholds V_{TL} , V'_{TL} are crossed early and late, respectively, causing a longer than usual pulse on signal P2. The voltage V_C has not fully recovered by the time t_{p3} the next positive peak occurs, and hence the peak detection pulse on signal P1 is of reduced width, and its rising and falling edges are out of phase with those of other cycles. Similarly, during this period of reduced V_C , the baseline crossing points, detected by the crossing of voltages V_{ZC} , V'_{ZC} are out of phase with those

of other cycles, and do not correspond to the location at which the mains input voltage actually crosses the zero voltage level.

Figure 10 shows another consequence of the independence of the reference voltages from the circuit supply voltage defined by V_C . V_M is the composite voltage supplied to the control circuit while a low range alternating input voltage is present. Neither of the peak detection signals P1 and P2 produce pulses, as the signal V_M never exceeds V_{TH} or V_{TL} . The automatic doubler/bridge circuit is in voltage doubling rectification mode. However, as in figure 9, at time t_A the voltage V_C drops by an amount ΔV_C . As discussed above, the magnitude of V_M reduces, and at the negative peak at time t'_{p2} , the lower threshold V_{TL} is crossed, and signal P2 produces a pulse, indicating a high range voltage. This will immediately stop voltage doubling mode, causing a temporary reduction in the output voltage of the rectifier circuit. Analogous problems may be encountered during a temporary increase in the value of V_C , and hence V_{DC} . Such behaviour is unacceptable for system level performance.

A voltage reference circuit will be discussed, wherein the reference voltages are affected by variations in the magnitude of the power supply voltage V_C , such that there is always a fixed voltage between each of them and the DC component V_{DC} of the composite voltage V_M .

This is achieved by ensuring that the reference voltages track the DC offset V_{DC} of the composite voltage V_M . As for the example above, this voltage may be $\frac{1}{2}V_C$. The DC component could, however, be any fraction of V_C , chosen such that the whole possible range of V_M lies within the appropriate permitted range.

The definition of V_M may be written:

$$V_M = \frac{1}{2}V_C + n \cdot V_{LN},$$

where n is a fraction suitably chosen such the whole range of V_M lies within the range between the nominal values of V_L and V_{ss} , for the highest expected value of V_{LN} .

As the voltages we require to detect for peak and zero crossing detection correspond to certain values of the AC input voltage V_{LN} , these may be detected

by detecting the crossing of certain reference voltages corresponding to values of $n.V_{LN}$. By defining each reference voltage as tracking the DC offset voltage V_{DC} , plus a certain fixed voltage V_p which is the required certain value of $n.V_{LN}$, the required reference voltages are obtained. These reference voltages will then vary in magnitude exactly as the DC offset voltage V_{DC} varies. Both the DC offset voltage V_{DC} and the certain fixed voltage V_p are referenced to the ground voltage V_{ss} . The passing of a reference voltage then corresponds to:

$$V_M = \frac{1}{2}V_C + n.V_{LN} = \frac{1}{2}V_C + V_p;$$

$$n.V_{LN} = V_p.$$

Figure 11 shows the required function of the voltage reference circuit. All necessary reference voltages, V_{TH} , V'_{TH} , V_{ZC} , V'_{ZC} , V'_{TL} , V_{TL} track variations in $\frac{1}{2}V_C$ in this example, or any other value that V_{DC} may take. As the voltage V_C varies, the values of all the reference voltages vary, keeping a constant difference between each reference voltage and V_{DC} . Voltage reference sources such as the amplified bandgap reference discussed above will supply a voltage $x.V_{BG}$, constant with respect to the ground voltage V_{ss} . This, however, varies in magnitude when considered with respect to V_{DC} .

Figure 12 shows a circuit embodying such a voltage reference. A buffer amplifier A1 receives the DC offset voltage V_{DC} , and supplies it to node 40, at the centre of a resistive divider network comprising resistors R_7 , R_8 , R_9 . Several nodes 42, 44, 46, 48 are tapped from this resistive divider network. This network is connected in series, and forms a first circuit branch, with two p-channel MOS transistors QP1, QP2 in series, connected also to the positive-most supply voltage V_+ , and two n-channel MOS transistors in series QN1, QN2, also connected to a ground voltage V_{ss} .

A second, parallel, circuit branch has two p-channel MOS transistors QP3, QP4 and two n-channel transistors QN3, QN4 in series respectively between V_+ and V_{ss} . The p-channel transistors QP3, QP4 have their gates connected to the gates of transistors QP1, QP2 respectively, and to their own source terminals. The n-channel transistors QN3, QN4 have their gates connected to the gates of transistors QN1, QN2, respectively.

A third parallel circuit branch comprises two n-channel MOS transistors

QN5, QN6 connected in series, the source of QN6 being connected to the ground voltage V_{ss} , the drain of QN5 being connected to the output of a constant current generator IG, which generates a constant current I_{ref} through the transistors QN5, QN6. The gates of transistors QN5 and QN6 are connected to the gates of transistors QN3, QN4 respectively, and also to their own respective drain terminals.

The constant current generator IG passes its reference current I_{ref} through the two n-channel transistors QN5, QN6. These are each connected as a current mirror with transistors QN3, QN4 respectively. An identical current, I_{ref}' , therefore flows through the second circuit branch. This second circuit branch consists of four transistors QP3, QP4, QN3, QN4, each connected as a current mirror with a corresponding transistor in the first circuit branch.

The first circuit branch comprises an upper portion, including transistors QP1, QP2, and resistors R7, R8 as far as node 40; and a lower portion comprising the rest of the branch, that is resistors R9, R8 from node 40, and transistors QN1, QN2. The current mirrors comprising transistors QP3, QP1, QP4, QP2 cause a current I_{ref}'' , equal to I_{ref} , to flow in the upper part of the first circuit branch. The current mirrors comprising transistors QN3, QN1, QN4, QN2 cause a current I_{ref}''' , equal to I_{ref} , to flow in the lower portion of the first circuit branch. Hence, an identical current flows in each portion of the first circuit branch, and no current flows into or out of the output of amplifier A1.

The output of the buffer amplifier A1 holds the voltage V_{DC} at node 40. The voltages at each of the nodes 42, 44, 46, 48 are then accurately held at voltages $V_{DC} \pm I_{ref}R_t$, where R_t is the total resistance between the node in question and node 40. Hence, by selecting appropriate values for resistors R_7 , R_8 , R_9 , all of which may be adjustable, accurate reference voltages are available for any desired value, with respect to the DC component V_{DC} . The difference between the voltage at each node and node 40 is fixed by the constant current source output I_{ref} , and the adjustments and values of resistors R_7 , R_8 , R_9 . If only voltages greater than V_{DC} or only voltages less than V_{DC} were required, resistors would only be necessary in either the upper or the lower portions of the first circuit branch.

The use of two current mirrors in series at each mirroring step (a "cascode stage") ensures a greater matching accuracy than would have been achieved by

using a single current mirror in their place.

Although this circuit can provide the required voltage references of $V_{DC} \pm V_p$, it suffers from variations in the absolute value of the resistors, when implemented in integrated form, together with variations of resistance with temperature. The current source IG and the transistors may suffer from matching errors and tolerance deviations.

Figure 13 shows a second circuit for a voltage reference capable of the required functionality, which does not suffer from the above limitations. A bandgap voltage reference BG is supplied by the two available power supply voltages, V_4 , V_{ss} which have a difference of V_C . Its output voltage V_{BG} is applied to the input of buffer amplifier A2, whose output will also be at voltage V_{BG} . A resistive divider network comprising resistors R_{10} , R_{12} provides a DC voltage V_i to a non-inverting input of an opamp A3. An inverting input of opamp A3 is connected to the output of the buffer amplifier A2, via a resistor R_{13} . A feedback resistor R_{14} is connected between the output V_o and the inverting input of the operational amplifier A3. As is normal with operational amplifiers, the inverting terminal will be at the same voltage as the non-inverting input.

The output voltage V_{BG} of the voltage reference BG is at a fixed value with respect to the voltage V_{ss} , and is independent of any fluctuations in the supply voltage V_C . V_i is a fraction of V_4 with respect to V_{ss} and therefore proportionately follows any variation in the supply voltage V_C .

Considering the currents (which must be equal) through resistors R_{13} , R_{14} ,

$$\frac{V_i - V_{BG}}{R_{13}} = \frac{V_o - V_i}{R_{14}}$$

$$V_i (1 + R_{14}/R_{13}) - V_{BG} (R_{14}/R_{13}) = V_o.$$

In this expression, the V_i term is the DC offset term which must correspond to V_{DC} and the V_{BG} term corresponds to the fixed voltage V_p . The operational amplifier A3 thus performs both multiplication of V_{BG} by (R_{14}/R_{13}) to obtain the fixed voltage V_p and offsets V_p by the voltage V_{DC} . To fit the example, where $V_{DC} = \frac{1}{2}V_C$,

$$V_i(1 + R_{14}/R_{13}) = \frac{1}{2}V_C; V_i = \frac{1}{2}V_C \cdot R_{13}/(R_{13} + R_{14}).$$

This may be arranged by fixing $R_{12} = R_{13}$ and $R_{10} = 2R_{14} + R_{13}$.

As V_i is directly proportional to V_C and provides a component of $\frac{1}{2}V_C$ at the output of amplifier A3, any variation ΔV_C of the voltage V_C will be reflected with a variation of $\frac{1}{2}\Delta V_C$ at the output of amplifier A3. The V_{BG} element remains unaffected by the variation in V_C , providing the required reference voltage V_{BG} , with reference to V_{ss} . The output voltage of amplifier A3 is therefore at a voltage V_p less than V_C . The voltage V_p never changes, whatever variation occur in V_C , provided that a minimum voltage is maintained, as required to ensure correct operation of the voltage reference BG. This minimum voltage may be around $4\frac{1}{2}V$. The output of amplifier A3 therefore fulfills the function of providing a voltage reference which varies with V_{DC} , but which maintains a fixed value with respect to V_{DC} , independent of variations of V_C .

This circuit allows the generation of any voltage below V_{DC} . To provide the required reference voltages above V_{DC} , an inverting buffer amplifier is used.

Figure 13A shows an inverting buffer amplifier, used to provide the threshold voltages above V_{BG} . An operational amplifier A4 has a non-inverting input connected to V_{DC} , which may be set by a resistive divider between the power supplies. Equal resistances R_{15} , R_{16} are connected between the inverting output and an output of amplifier A4, and the inverting input of amplifier A4 and the output of amplifier A3, figure 13, respectively.

As the output of amplifier A3, figure 13, is $V_{DC} - V_p$, and amplifier A4 is using V_{DC} as a virtual ground, the output of this amplifier A4 will be $V_{DC} + V_p$, providing a reference voltage greater than V_{DC} , symmetrical with the corresponding reference voltage less than V_{DC} .

By using this circuit to supply both positive and negative peak detection references V_{TH} , V_{TL} , a resistive divider may be set up between the outputs of A3 and A4, to supply each of the required reference voltages. This may advantageously combined with the function of resistors R_{15} , R_{16} .

Figure 13B shows a circuit allowing all required threshold voltages, V_{TH} , V'_{TH} , V'_{ZC} , V_{ZC} , V'_{TL} , V_{TL} , to be obtained from the two peak detection threshold values V_{TH} , V_{TL} . Circuit elements which are identical to those of figures 13 and

13A have identical reference symbols. A first resistive divider comprising resistors R_{17} , node 50, resistor R_{18} , node 52 and resistor R_{12} is connected between the supply V_4 and ground V_{ss} . A second resistive divider network comprising: resistor R_{19} ; node 54; resistor R_{20} ; node 56; resistor R_{21} ; node 58; resistor R_{22} ; node 60; resistor R_{23} ; node 62 and resistor R_{24} is connected between the outputs of amplifiers A3, A4 respectively. In the first resistive divider, resistors R_{17} , R_{18} jointly perform the function of resistor R_{10} in figure 13, and by fixing $R_{18} = R_{14}$, and $R_{17} = R_{13} + R_{14}$, the required value of $V_{DC} = \frac{1}{2}V_C$ is obtained at node 50 for biasing the non-inverting input of amplifier A4, while node 52 maintains the correct voltage V_i as discussed above.

In the second resistive divider, by fixing $R_{19} = R_{24}$; $R_{20} = R_{23}$; $R_{21} = R_{22}$, each pair of reference voltages (V_{TH} and V_{TL} ; V'_{TH} and V'_{TL} at nodes 62, 54; V'_Z and V_Z at nodes 56, 60) are symmetrical about V_{DC} , and the voltage at node 58 is equal to the DC component V_{DC} , as required for proper biasing of amplifier A4. Resistors R_{19} , R_{20} , R_{21} together perform the function of R_{15} in figure 13A, and resistors R_{22} , R_{23} , R_{24} perform the function of R_{16} in figure 13A.

Each of the reference voltages described is then connected to a respective voltage comparator to allow peak and zero crossing detection to be carried out, as described above.

Figure 14 shows a third embodiment of a DC voltage supply circuit according to the invention, using discrete components. Again, features similar to those in figure 8 have similar reference numbers.

As in the previously described implementations, a half-wave rectifier comprises diode D_s , resistor R_4 , node 22 and capacitor C, respectively connected in series between the live line L and the neutral line N. A three terminal regulator X1 has: a ground input connected to node 22; a voltage input connected to the neutral line N; and a voltage output connected a node 68. Two resistors R_1 , R_2 are connected in series between between the live line L and node 22 respectively. The two resistors share a common node 70. A further resistor R_3 is connected between the node 68 and the node 70. A resistor R_{Z1} , a node 72, zener diode Z_{TH} , node 73, zener diode Z_{TL} , node 74 and resistor R_{Z2} are respectively connected in series

between node 68 and node 22. Two comparators A5, A6 have power supply connections connected to nodes 68 and 22. A non-inverting input of A5 is connected to node 70, as is an inverting input of A6. An inverting input of A5 is connected to node 72, and a non-inverting input of A6 is connected to node 74.

A signal amplifier and voltage shifter 76 has two inputs each connected to an output of A5 and A6. The signal amplifier and voltage shifter 76 has an output connected to a gate input of triac T.

The zener diodes Z_{TL} , Z_{TH} set the low and high peak detection thresholds V_{TL} and V_{TH} , respectively. Resistors R_{Z1} , R_{Z2} supply a zener diode bias current, and are chosen such that the node 73 between the zener diodes is at the DC offset voltage V_{DC} . Nodes 72 and 74 are then held at voltages greater and less than V_{DC} , respectively, by voltages equal to the breakdown voltages of the zener diodes Z_{TH} , Z_{TL} , respectively. The comparators A5, A6 each produce a high output when the voltage at node 70 exceeds the voltage at node 72, or falls below the voltage of node 74, respectively. The voltage at node 70 is a composite voltage, as discussed for other embodiments of the invention, being a scaled representation of the AC input voltage, supplied by the series connection of R_1 , R_2 , added to a DC offset voltage V_{DC} provided by a DC current supplied by R_3 , through R_2 . The diode D_5 , resistor R_4 and capacitor C function as described for other embodiments of the invention, to provide a DC voltage across capacitor C. This DC voltage is regulated by X1, to fix V_{ss} , node 22, at a fixed voltage, for example 9V, less than the neutral line N voltage.

The AC input voltage V_{LN} is hence scaled down and voltage shifted, allowing detection of both high and low peaks, gaining the advantages described of full-wave voltage sensing, in an embodiment using discrete components.

The signal amplifier and voltage shifter 76 produces gate pulses to the triac, T when no output pulses are produced by A5, A6, - indicating a low-range AC input voltage, and so enabling voltage doubling rectification mode of an associated doubler/bridge rectifier - and suppresses such gate pulses when output pulses from A5, A6 are present - indicating a high-range AC input voltage, and so ensuring that bridge rectification mode is used.

Figure 15 shows the voltages V_i , V_i' at node 70, for low-range and high-

range AC input voltages, respectively. The scaled AC input voltage is shifted by DC offset V_{DC} , and compared with the upper and lower thresholds V_{TH} , V_{TL} . The outputs P3, P4 of comparators A5, A6, respectively, correspond to a high voltage input V_I' . R denotes the allowed range of input voltages to the control circuit.

However, the embodiment of the invention using discrete components does not include the filtering and other functions included in integrated circuit implementations. Zener diode breakdown voltages have a tolerance of around $\pm 10\%$, and so may provide less accurate peak voltage detection than other embodiments described.

The additional data points introduced by providing "dual cycle" detection, i.e. detection during both positive and negative excursions, of the range of the AC input voltage lead to more efficient detection of the voltage range and more efficient filtering, applied to the whole cycle.

By using the method described, even the highest AC peak to peak voltages may be accommodated within the permitted voltage range and hence subjected to the full wave zero crossing detection and voltage sensing described. This results in faster, more reliable detection of AC voltage level and hence many of the drawbacks described with reference to the single cycle (i.e. one excursion only per cycle) detection scheme are overcome.

While the discussion herein has referred to mains input AC voltages with a baseline at the zero volts level, the circuits of the invention may equally be used with input AC voltages with non-zero baseline levels, with suitable adjustment of resistor values and voltage threshold levels.



What is claimed is:

1. A reference voltage generation circuit for generating reference voltages at a fixed voltage with respect to a varying voltage including a reference voltage generator generating a reference voltage which is constant with respect to a ground voltage, a voltage multiplication circuit for multiplying the reference voltage by a predetermined multiple to provide the fixed voltage, and an offset circuit for offsetting the fixed voltage by the varying voltage.

2. A reference voltage generation circuit according to claim 1 wherein the varying voltage is derived from a supply voltage to the circuit.

3. A reference voltage generation circuit according to claim 2 wherein the voltage multiplication circuit and the offset circuit are provided by a first operational amplifier with an input resistor connected between a first input and the reference voltage and a feedback resistor connected between the first input and an output of the first operational amplifier; a resistive divider being connected between the supply voltage and the ground voltage, with a node thereof connected to a second input of the first operational amplifier.

4. A reference voltage generation circuit according to claim 3 further comprising a second operational amplifier, with a feedback resistor connected between a first input and the output, a second resistor connected between the first input and the output of the first operational amplifier, and having a second input connected to receive the varying voltage.

5. A reference voltage generation circuit according to claim 1 wherein the reference voltage generator is a bandgap voltage reference powered by the supply voltage, and is connected to an input of a buffer amplifier, the output of the buffer amplifier providing the reference voltage.

6. A reference voltage generation circuit for generating reference voltages at a fixed value with respect to a varying voltage including a fixed reference current generator generating matching currents through two series portions of one circuit branch, at least one of said series portions including a resistive element, a node between the two series portions being connected to receive the varying voltage.

7. A reference voltage generation circuit according to claim 6 wherein the varying voltage is derived from the supply voltage to the circuit.

8. A reference voltage generation circuit according to claim 7 wherein the circuit branch comprises a first transistor of a first channel type, a resistive element, and a first transistor of a second channel type respectively connected between the supply voltage and a ground voltage.