

"POWER SUPPLY CIRCUIT"

The invention relates to a power supply a circuit for generating an output d.c. voltage, comprising a generator for generating a square-wave voltage and a peak-peak rectifier coupled to the generator for producing across a smoothing capacitor the output voltage for a load connected to the capacitor.

Such a power supply circuit is disclosed in German Patent Application 2 155 076. When in this known circuit the load fluctuates considerably then the instants at which the edges of the square-wave voltage occur may be affected thereby. These edges are then shifted in dependence on the load, which may be a disadvantage, for example if the signal from the square-wave generator is used elsewhere. If, for example, the load is in the form of a class-B audio section in a picture display device, for example a television receiver, whilst the power supply circuit also supplies energy to the line deflection circuit, then the length of the lines displayed on the display screen may vary at the rate of the audio signal, which is very disturbing.

The invention has for its object to provide a power supply circuit of the above-mentioned type, wherein the edges of the square-wave voltages are substantially not affected by the load.

The invention provides a power supply circuit for converting an input d.c. voltage into a first output d.c. voltage to which a first load is connected and into a second output d.c. voltage to which a second load is connected, comprising the series arrangement of an inductor and a controllable switch, which series arrangement is connected to a terminal for the input voltage, said switch being, in operation, alternately in the conductive and in the non-conductive states, the first output voltage being derived from a square-wave voltage present across the inductor, the conduction periods of the switch being controlled by means of a control circuit connected to a control electrode of the switch for obtaining for the first output voltage a value which is substantially independent of variations of the input voltage and/or the first load, the power supply circuit further comprising a

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tuned rectifier circuit coupled to the inductor for producing the second output voltage across a smoothing capacitor, said tuned rectifier circuit comprising a series resonant network and a peak-peak rectifier connected thereto, a half cycle of the sinusoidal current flowing through the series resonant network not exceeding in time the interval between two consecutive edges of the square-wave voltage present across the inductor.

The measure according to the invention provides that current does not flow through the rectifier at the occurrence of the subsequent edge of the square-wave voltage, so that this edge is substantially not shifted in dependence on the current through the rectifier.

The invention will now be further described by way of example with reference to the accompanying drawings, in which

Figure 1 shows a basic circuit diagram for explaining the present invention,

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Figure 2 shows the circuit diagram of a first embodiment of a switched-mode power supply circuit according to the invention,

Figure 3 shows wave-forms occurring in the circuit
5 of Figure 2,

Figure 4 shows the circuit diagram of a second embodiment of a switched-mode power supply circuit according to the invention,

Figure 5 shows the circuit diagram of a third
10 embodiment of a switched-mode power supply circuit according to the invention,

Figure 6 shows wave-forms occurring in the circuit shown in Figure 5 and

Figure 7 shows the circuit diagram of a fourth
15 embodiment of a switched-mode power supply circuit according to the invention.

In the basic circuit diagram of Figure 1, E denotes a generator which generates a square-wave voltage. Connected to generator E is a series resonant network which in its
20 most simple form consists of an inductance L and a capacitor C, the internal impedance of generator E being disregarded. By means of its other end network L, C is connected to the anode of a diode D_1 and to the cathode of a diode D_2 . The cathode of diode D_1 is connected to a smoothing capacitor
25 C_1 , whose other end is connected to the anode of diode D_2 and to that terminal of generator E not connected to network L, C. A load which can be represented as a resistor R_1 is arranged in parallel with capacitor C_1 .

If in the voltage generated by generator E an
30 ascending edge occurs, then the voltage at the junction between diodes D_1 , D_2 and network L, C also increases, causing diode D_1 to become conductive. A current which has a sinusoidal variation because of the series resonance flows through elements L, C and D_1 . This current flows to
35 capacitor C_1 to recharge it. After having attained a maximum, the current decreases and becomes zero at a given instant. At that instant inductance L has no further energy, so that no current flows anymore through network

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L, C, while diode D_1 becomes non-conducting. The resonant frequency is chosen in such a way that this instant precedes the instant at which the subsequent, descending edge of the square-wave voltage of generator E occurs. This means that a half-cycle of the sinusoidal current is shorter than the time interval between the two considered edges. The choice made ensures that no current depending on load R_1 , flows through generator E at the instant at which the descending edge is produced, as the amplitude of the sinusoidal current depends on the value of load R_1 .

During the time in which the sinusoidal current flows, the voltage at the junction between inductance L and capacitor C varies in accordance with a cosinusoidal function, whereafter this voltage remains equal to the voltage of capacitor C_1 , which may be assumed as being constant during a short period of time. It can be seen that the value of this voltage at not too low a value of resistor R_1 is equal to the value of the voltage produced by generator E. If now the descending edge occurs in this voltage, then the voltage at the junction between diodes D_1 , D_2 and network L, C also decreases, causing diode D_2 to become conductive. A current flows through elements L, C and D_2 , and that in the opposite direction relative to the preceding current. This current is sinusoidal and as the capacitance of capacitor C_1 is in the majority of cases many times larger than the capacitance of capacitor C, the frequency of this current is substantially the same as the frequency of the preceding sinusoidal current. Consequently, the duration and amplitude thereof are also substantially the same, as the average value of the current flowing through network L, C is zero between two ascending edges of the square-wave voltage of generator E. The current through diode D_2 stops flowing before the next ascending edge of the square-wave voltage occurs. During the period of time in which this current flows, the voltage at the junction between inductance L and capacitor C varies in accordance with a cosinusoidal function, whereafter this voltage becomes zero.

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From the preceding it will be apparent that the voltage across capacitor C_1 provided the value of resistor R_1 is not too low, is substantially equal to the amplitude of the square-wave voltage of generator E, which results from the fact that diodes D_1 and D_2 form a peak-peak rectifier. The voltage applied to resistor R_1 is constant if the said amplitude is constant. It can also be seen that the load does not influence generator E. Without series resonance, that is to say at a large value of the capacitance of capacitor C, for example to the same order of magnitude as the capacitance of capacitor C_1 which is indeed a smoothing capacitor, and if a peak rectifier is provided instead of a peak-peak rectifier, current would flow in Figure 1 through generator E at the occurrence of the edges of the signal from the generator.

The circuit of Figure 2 comprises a switched-mode power supply circuit of the series (forward) type. The collector of an npn-switching transistor Tr is connected to the positive terminal of an input d.c. voltage source whose voltage V_B is smoothed by means of a capacitor C_0 and is for example derived from electric mains by means of rectification. The emitter of transistor Tr is connected to the cathode of a rectifier D_3 and to an end of the primary winding L_1 of a transformer T, whose other end is connected to a smoothing capacitor C_2 . The anode of rectifier D_3 , the other terminal of capacitor C_2 and also the negative terminal of the input voltage source are connected to ground. A load which can be represented as a resistor R_2 is arranged in parallel with capacitor C_2 . Switching pulses which alternately set the transistor to the conductive and the non-conductive states are applied to the base of transistor Tr by a driver stage Dr.

Figure 3a show the variation of the voltage present across winding L_1 as a function of the time, while Figure 3b shows the variation of the emitter current of transistor Tr and Figure 3c the variation of the current of rectifier D_3 . During the time transistor Tr conducts, the emitter current thereof increases in a substantially

linear way and flow via winding L_1 to capacitor C_2 and load R_2 , while rectifier D_3 is cut-off. During the period of time the transistor is non-conductive, the current through winding L_1 also flows through rectifier D_3 and decreases in a substantially linear way. A square-wave voltage which during the period of time transistor Tr conducts has the value $V_B - V_O$ and during the period of time the transistor is non-conductive has the value $-V_O$ is present across the winding L_1 . V_O is here the value of the output voltage across capacitor C_2 . This voltage is fed-back to stage Dr to control the duration of the switching pulses produced by this stage, causing voltage V_O to be kept substantially constant.

All this is well known to a person skilled in the art. Secondary windings are provided on the core of transformer T . In known manner a supply voltage can be derived from one of these windings, L_3 , for a load, not shown. The network formed by elements C , D_1 , D_2 , C_1 and R_1 is connected to another secondary winding, L_2 . The capacitance of C is chosen such that the capacitor and the leakage inductance of transformer T form a series resonant network, the coupling between windings L_1 and L_2 being less than 1. In operation, a square-wave voltage is present across winding L_2 , so that the part of Figure 2 which includes winding L_2 and the circuit portions to the left thereof operates as the generator E of Figure 1, whereas the said leakage inductance functions as the inductance L of Figure 1. In the same way as in Figure 1, a sinusoidal current flows through capacitor C , which current also flows through diode D_1 . This occurs during the period of time transistor Tr conducts, in which period supply energy is applied to capacitor C_1 . The resonant frequency is chosen such that the current stops flowing before the instant at which transistor Dr is cut-off. During the conduction period of rectifier D_3 a sinusoidal current flows through diode D and capacitor C and this current stops flowing before ² transistor Tr is again adjusted to the conducting state. Figure 3d shows both the half cycles

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of the sinusoidal current through capacitor C.

Since a sinusoidal current flows through the secondary winding L_2 of transformer T, the current through the primary winding comprises a sinusoidal component. This component, which is shown in Figure 3b and 3c by means of a broken line flows simultaneously with the current through winding L_2 . The sinusoidal component is added to the emitter current of transistor Tr, while the sinusoidal component flows through rectifier D_3 in the opposite direction and is consequently subtracted from the linear current. When voltage V_B and/or load R_2 and/or the load of the supply network connected to winding L_3 change, the duration of the time during which transistor T_3 conducts changes. The part of the circuit comprising load R_1 will not affect the operation of the rest of the circuit if the period of time in which the sinusoidal current component flows through transistor Tr does not exceed the shortest anticipated conduction period of the transistor, and if the period of time in which the sinusoidal current component flows through rectifier D_1 does not exceed the shortest anticipated conduction period of the rectifier, i.e. the time the transistor is non-conductive. A still further condition is that the sinusoidal component flowing through the rectifier must not have such a large amplitude that the rectifier is cut-off. It will be clear to a person skilled in the art that it is possible to design a circuit which satisfies these conditions. Herein, the tuning frequency of the series resonant network and consequently the capacitance of capacitor C is a parameter to be chosen. If necessary, an inductance can be provided in series with capacitor C and with the leakage inductance of transformer T. In a border-line case the tuning frequency is so low that the time in which current flows through the resonant network is of the same duration as the shortest period of time in which transistor Tr conducts. In this case the interval in Figure 3d between the positive and the negative portions is reduced to zero. In a similar way, in a border-line case, the time in which current

flows through the series resonant network is of the same duration as the shortest period of time in which transistor Tr is non conductive, which causes the interval in Figure 3d between the negative and the positive portions to be reduced to zero. The maximum value of the period of the sinusoidal current must therefore be less than the period of time which is the shorter: either the minimum conduction period or the minimum period of time in which the transistor is non-conductive. This determines the lowest possible value of the tuning frequency. Towards the side of the high-frequencies, the border-line case is the case in which the tuning frequency is so high that the maximum value of the sinusoidal current component reaches the value at which the rectifier becomes non-conductive or reaches the value which is still permissible for the transistor, as a larger amplitude is associated with a shorter pulse duration for the sinusoidal current.

As the change in the current through the transistor caused by the sinusoidal component ends prior to or at the end of the conduction time of the transistor no change occurs in the saturation state of the transistor just before it is switched-off, so that the turn-off period is substantially not affected. So a shift of the turn-off instant as a function of load R_1 does not occur, which would indeed be the case in the event of a large capacitance of capacitor C , that is to say at a very low resonant frequency, and when a peak rectifier were used instead of the peak-peak rectifier D_2, D_3 , in which case the total current to capacitor C_2 were changed, which would necessitate controlling of transistor Tr . It will be noted that the operation of the circuit is not changed when the series resonant network formed by capacitor C and an inductance is not connected inductively to winding L_1 but directly, or if it is connected to the cathode of rectifier D_3 , as at this cathode a square-wave voltage is present whose edges coincide with those of Figure 3a, those edges not being affected by load R_1 , which also holds for the edges of Figure 3a. It will also be noted that

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the voltage across capacitor C_1 is not constant when voltage V_0 is substantially constant, but that it varies somewhat with fluctuations of voltage V_B . So a load which is capable of withstanding such a variation will be chosen for load R_1 .

The switched-mode power supply circuit of Figure 4 is of the parallel (flyback) type. This case the series network of transistor T and winding L_1 is also connected to source V_B , but rectifier D_3 is now connected to a secondary winding L_3 of transformer T. One end of capacitor C_2 is connected to the other electrode of rectifier D_3 and its other end to the other end of winding L_3 . The winding senses of windings L_1 and L_3 and the conductivity direction of rectifier D_3 are chosen such that current flows through the rectifier when transistor Tr is non-conductive and that the rectifier is non-conductive when the transistor conducts. The voltage V_0 across capacitor C_2 which is applied to load R_2 is kept substantially constant by controlling the conduction time of transistor Tr. Square-wave voltages whose edges occur simultaneously are present across windings L_1 and L_3 and across rectifier D_3 . The series resonant network and the peak-peak rectifier can therefore be connected to one of these voltages. In Figure 4 they are connected to a secondary winding L_2 of transformer T, the series inductance being provided by the leakage inductance. It can be seen that no influence is exercised on the rest of the circuit when the conditions are the same as in the circuit of Figure 1.

The invention can be employed with other, known switched-mode power supply circuits. Figure 5 shows a circuit which is known from the publication "Philips, Electronic components and materials: Technical publication 006", published in 1981. The circuit comprises the series arrangement of two diodes D_4 and D_5 . The cathode of diode D_4 is connected to a tap of an inductance L_0 , one end of which is connected to the positive terminal of source V_B . The anode of diode D_4 and the cathode of diode D_5 are connected to the anode of a further diode D_6 and to a capaci-

tor C_3 . The other end of capacitor C_3 is connected to the other end of inductance L_0 and to winding L_1 . The cathode of diode D_6 is connected to the other end of winding L_1 and to the collector of transistor Tr. A tuning capacitor C_4 is arranged in parallel with winding L_1 and the emitter of transistor Tr and also the anode of diode D_5 are connected to ground. The network comprising elements L_3 , D_3 , C_2 and R_2 is of a construction as shown in Figure 4 and is provided at the secondary side of transformer T.

The circuit of Figure 5 can be used to apply supply energy to the different parts of a picture display device, for example a television receiver. Transistor Tr is supplied with switching pulses of the line frequency and the conduction time of the transistor is controlled in dependence on the voltage V_0 across capacitor C_2 , as a result of which this voltage and consequently also the voltage across capacitor C_3 are kept substantially constant. During the major portion of the line period, the so-called trace period, either diode D_6 , or transistor Tr and diode D_5 , conduct, so that the voltage across winding L_1 is substantially constant. In the remaining portion of the line period, the so-called retrace period, both transistor Tr and diodes D_5 and D_6 are non-conductive. An oscillation is present in the resonant circuit formed by winding L_1 and capacitor C_4 . The similar oscillation present across winding L_3 is rectified by rectifier D_3 for the generation of voltage V_0 . A secondary winding L_4 of transformer T is connected to the base of a transistor Tr₁ which operates as a line-frequency switch in a line deflection circuit, not shown. Alternatively, transistor Tr₁ can be applied with control signals from stage Dr.

Figure 6a shows the variation as a function of the time of the voltage at the collector of transistor Tr and Figure 6b shows the corresponding variation at the junction A of diodes D_4 , D_5 and D_6 . In Figure 6c, the variation of the collector current of transistor Tr is plotted, while in Figure 6d the variation of the current through diode D_5 , in Figure 6e the variation of the current through

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diode D_4 and in Figure 6f the variation of the current through diode D_6 have been plotted. At an instant t_1 transistor Tr is rendered conductive, as a result of which diode D_6 also conducts. After the current which flows through winding L_1 and has a substantially linear variation during the trace period has reversed its direction, diode D_6 is rendered non-conductive at an instant t_2 , whereafter diode D_5 carries current. The current through diode D_5 also flows through capacitor C_3 , winding L_1 and transistor Tr. At the instant t_3 at the end of the trace period transistor Tr is rendered non-conductive as a result of which also diode D_5 becomes currentless, while diode D_4 becomes conductive. Between instants t_1 and t_3 point A is clamped to ground. At the end instant t_4 of the retrace period diode D_6 becomes conductive. Until the instant t'_1 at which transistor Tr is again rendered conductive the voltage at the collector remains at substantially the same level as at the tap of inductance L_0 .

An isolating capacitor C_5 is connected to point A whose other end is connected to the primary winding L_5 of a transformer T_1 . Winding L_2 is in the form of a secondary winding of this transformer and elements C, D_1 , D_2 , C_1 and R are connected in the same way as in Figures 1, 2 and 4. A current which varies similarly as in Figure 3d flows through winding L_2 which causes a sinusoidal current component shown in Figure 6 by means of broken lines to flow in some elements of the circuit. After instant t_1 a sinusoidal component flows through winding L_5 , capacitor C_5 , diode D_6 and transistor Tr. This causes diode D_6 to become currentless at an instant located somewhat after instant t_2 . At the same instant diode D_5 becomes conductive. The sinusoidal component flows through diode D_5 from the cathode to the anode, the diode being kept in the conducting state by the larger current to capacitor C_3 , winding L_1 and transistor Tr. The said component stops flowing prior to instant t_3 . After instant t_3 a sinusoidal current component flows through winding L_5 and capacitor C_5 in the opposite

direction. This component flows through diode D_4 , which is kept in the conducting state by the larger charging current of capacitor C_3 , from the cathode to the anode and stops flowing before the instant t'_1 at which transistor Tr is rendered conductive one cycle after instant t_1 .

Figure 6 shows that the operation of the circuit is substantially not affected by the addition of the circuit portion comprising load R_1 , if the same conditions as in the foregoing are satisfied, that is to say if the different edges are not shifted as a function of R_1 and no switching element is prematurely rendered non-conductive. The tuning frequency of the series resonant network is determined by the two capacitors C and C_5 . It will be obvious that the series network of elements C_5 and L_5 may alternatively be provided between point A and a point on inductance L_0 , for example the tap to which diode D_4 is connected, or to the end connected to capacitor C_0 , as a square-wave voltage whose edges also occur at instants t_1 and t_3 is present between the said points.

A similar voltage is also present across inductance L_0 , which functions as a charging coil. Diode D_4 does not conduct between instants t_1 and t_3 , while point A is connected to ground so that the voltage across inductance L_0 is equal to $V_B - V_C$, V_C being the voltage of capacitor C_3 . Diode D_4 conducts between instants t_3 and t'_1 and the voltage across inductance L_0 is equal to $\frac{V_C}{1-n}$ where n is the ratio between the number of turns of inductance L_0 to the left of the tap in Figure 5 and the total number of turns of the inductance. In Figure 7 inductance L_0 is the primary winding of a transformer T_2 whose winding L_2 is a secondary winding to which elements C , D_1 , D_2 , C_1 and R_1 are connected in a similar way as in Figures 2, 4 and 5. In all further respect the circuit of Figure 7 is identical to the circuit of Figure 5, it being possible to omit capacitor C_5 and transformer T_1 , and it operates in the same way.

As the circuit of Figure 5 as well as the circuit of Figure 7 drive the line deflection circuit, the maximum duration of the conduction time of transistor Tr is equal

to approximately 52 μ s, i.e. the duration of the trace period at a line period of approximately 64 μ s (European and United States television standards). So the minimum duration of the non-conductive period is approximately 12 μ s. Transistor Tr must conduct without fail in the centre of the trace period, so that the minimum duration of the conduction period is approximately 26 μ s. From this it will be obvious that the minimum duration of the half cycle of the sinusoidal component is approximately 12 μ s, which corresponds to a maximum resonant frequency of approximately 41.7 kHz. In practice, the maximum conduction time of transistor Tr is approximately 44 μ s, so that the minimum duration of the non-conductive period is approximately 20 μ s, which corresponds to a series resonance of approximately 25 kHz. Such a resonance is used in a practical embodiment of the circuit shown in Figure 7, the capacitance of capacitor C, which depends on the leakage inductance of transformer T₂ being less than approximately 5 μ F and the voltage of capacitor C₃ being kept substantially constant at approximately 100 V at variations of the mains voltage between 160 and 260 V and a nominal value of 220 V. Capacitor C₁ had a capacitance of 2000 μ F and load R₂ was in the form of the supply power for a class-B audio section having a continuous power of 2 x 15W, i.e. a section for which the supply voltage need not be constant, whereas the rest of the receiver was supplied with energy with the aid of transformer T.

It will be obvious that the invention may alternatively be used in variations of the described embodiments of generator E. The nature of the different switches is not important. Thus, the transistors may be replaced by gate turn-off switches. The peak-peak rectifier shown in Figures 1, 2, 4, 5 and 7 may alternatively be constructed in a different, known way.

CLAIMS:-

1. A power supply circuit for converting an input d.c. voltage into a first output d.c. voltage to which a first load is connected and into a second output d.c. voltage to which a second
5 load is connected, comprising the series arrangement of an inductor and a controllable switch, which series arrangement is connected to a terminal for the input voltage, said switch being, in operation, alternately in the conductive and in the non-conductive states, the first output voltage being derived from a square-wave voltage
10 present across the inductor, the conduction periods of the switch being controlled by means of a control circuit connected to a control electrode of the switch for obtaining for the first output voltage a value which is substantially independent of variations of the input voltage and/or the first load, the power supply circuit
15 further comprising a tuned rectifier circuit coupled to the inductor for producing the second output voltage across a smoothing capacitor, said tuned rectifier circuit comprising a series resonant network and a peak-peak rectifier connected thereto, a half cycle of the sinusoidal current flowing through the series
20 resonant network not exceeding in time the interval between two consecutive edges of the square-wave voltage present across the inductor.

2. A circuit as claimed in Claim 1, in a further rectifier is coupled to the switch, which further rectifier is in the
25 conductive state when the switch is in the non-conductive state and is non-conductive when the switch is conductive, the peak-peak rectifier being connected via the series resonant network for rectifying a square-wave voltage present across the further
30 rectifier or a square-wave voltage whose edges occur simultaneously therewith, the conduction time of the switch and the conduction time of the further rectifier both being not shorter than the half cycle period of the sinusoidal current flowing through the series resonant network.

3. A circuit as claimed in Claim 2, in which the series
35 arrangement of an isolating capacitor and the primary winding of a



transformer is connected between two points between which the square-wave voltage is present, the series resonant network being connected to a secondary winding of the transformer and the series resonant frequency being determined in part by the isolating capacitor.

4. A circuit as claimed in Claim 1, in which the inductor forms the primary winding of a transformer, the series resonant network being connected to a secondary winding of the transformer.

5. A circuit as claimed in any of the preceding Claims, in which the peak-peak rectifier comprises the series arrangement of two diodes having the same forward directions, the series arrangement formed being arranged in parallel with the smoothing capacitor and the junction between the diodes being connected to the series resonant network.

6. A power supply circuit substantially as herein described with reference to Figures 2 to 7 of the accompanying drawings.

