

## Description

This invention relates to resonant regulator power supplies.

EP-A-107003 and EP-A-107770 each discloses a resonant power supply having a source of alternating voltage of controllable frequency, a resonant circuit excited by the source, means coupled to the resonant circuit for generating an output voltage and a control circuit responsive to the output voltage to control the frequency of operation of the source to regulate the output voltage.

The control circuit includes a limiting circuit for preventing the frequency of operation of the source passing through the resonance frequency of the resonant circuit. In EP-A-107003 the resonant circuit is a parallel resonant circuit. In EP-A-107770 the resonant circuit is a series resonant circuit.

FR-A-8007449 (US-A-4336584) relates to a resonant regulator which varies the frequency of operation to regulate the output voltage. There is no provision to avoid resonance.

A resonant regulator operating on the positive slope of the resonant transfer characteristic curve regulates in an operating frequency range below the resonance frequency of the resonant circuit. If the control circuit of the resonant regulator attempts to locate the operating point above resonance, regulation is lost since the feedback changes from negative to positive feedback. The frequency control loop is therefore designed to avoid placing the operating point of the regulator on the side of the resonance frequency curve producing positive feedback under all expected operating conditions.

The elements of the frequency control loop are subject to tolerances in the values of the resonant L and C components, to tolerances in the voltage feedback components, such as voltage divider resistors, and generally to tolerances throughout the control loop. Because of the large number of elements associated with the frequency control loop, it is relatively impractical to hold all tolerances small enough to insure that the operating point of the resonant regulator is below the resonance frequency under all foreseeable operating conditions. This is especially true when it is desirable to operate very close to the resonance frequency, where the slope of resonant transfer characteristic curve is steep and provides good loop response.

Aspects of the invention are specified in the claims, to which attention is invited.

In the Drawing:

FIGURE 1 illustrates a resonant regulator power supply embodying the invention; and  
FIGURE 2 illustrates resonant transfer characteristic curves associated with the operation of the circuit of FIGURE 1.

In resonant regulator 20 of FIGURE 1, a source 21 of AC mains voltage is coupled between input terminals 22 and 23 of a full-wave bridge rectifier 19, to develop a DC unregulated input voltage  $V_{in}$  between a supply terminal 24 and a current return or ground terminal 25 that is electrically nonisolated from mains source 21. Filtering of voltage  $V_{in}$  is provided by equal-valued, series-coupled, capacitors C1 and C2. The unregulated DC voltages  $V_{i1}$  and  $V_{i2}$ , developed across respective capacitors C1 and C2, are substantially equal in magnitude, at one-half the magnitude of voltage  $V_{in}$ . A voltage regulator 33 supplies a low DC voltage +V for the control circuitry of resonant regulator 20.

An LC resonant circuit 10 includes an inductor  $L_0$  and a capacitor  $C_0$  series coupled at one end to an intermediate supply terminal 26 via a DC blocking capacitor C3, and at the other end to a square-wave input terminal 30. Resonant circuit 10 is coupled to and excited by a source 40 of alternating, square-wave, input voltage  $V_{sq}$ , controllable in frequency f.

Square-wave voltage source 40 comprises a frequency controllable oscillator 41, that generates a square-wave oscillator voltage  $V_{osc}$ , a driver stage 42, and push-pull switches S1 and S2. To assume a push-pull configuration, switch S1 is coupled between supply terminal 24 and square-wave input terminal 30, and switch S2 is coupled between input terminal 30 and nonisolated ground. In order to operate switches S1 and S2 in a push-pull manner, the output of driver 42 is inverted by an inverter 43 before being applied to switch S2. Capacitor C3 blocks any residual DC introduced by asymmetrical switching operation or by unequal values for capacitors C1 and C2.

In operation, square-wave input voltage  $V_{sq}$  excites resonant circuit 10 into oscillation to develop a generally sinusoidal supply voltage  $V_0$  across resonant capacitor  $C_0$ . Voltage  $V_0$  has a fundamental frequency at the exciting or operating frequency f of square-wave input voltage  $V_{sq}$ . The voltage developed across resonant inductor  $L_0$  is also a generally sinusoidal wave of frequency f that, however, exhibits step changes in voltage magnitude during leading and trailing edge transitions of voltage  $V_{sq}$ . The phasing between square-wave voltage  $V_{sq}$  and the sinusoidal components of the inductive and capacitive voltages varies with load and with AC mains voltage variations.

A primary winding W1 of a power transformer T1 is coupled across resonant capacitor  $C_0$  of resonant circuit 10. The inductance exhibited by winding W1 may affect the resonance frequency of resonant circuit 10, depending on its value relative to that of inductor  $L_0$ .

Voltage  $V_0$  is applied across primary winding W1 and develops sinusoidal output voltages across

tightly coupled secondary windings W3-W5. These voltages are rectified and filtered by respective elements 27-29 to develop respective DC supply voltages V1-V3 that energize respective load circuits not shown in FIGURE 1. Power transformer T1 also provides electrical shock hazard isolation between mains voltage source 21 and the load circuits energized by supply voltages V1-V3. Thus, the current return path or ground termination for the secondary side load circuits of transformer T1 is electrically isolated from ground 25 on the primary side.

A frequency control circuit 50 forms a negative feedback loop that regulates supply voltages V1-V3 with variations in main supply voltage and loading. To regulate the output voltages, one of the output voltages, illustratively voltage V1, is directly coupled to the emitter of a PNP error amplifier transistor Q1 via a level shifting, voltage reference, zener diode Z1. Voltage V1 is also coupled to the base of transistor Q1 via a voltage divider resistance network R1-R4, with the base being coupled to an adjustable intermediate point of the voltage divider.

The collector of transistor Q1 is coupled via a collector load resistor R8 to an input pin 1 of an opto-isolator amplifier U3 for developing a feedback voltage  $V_f$  across load resistor R16 coupled to an output pin 4. Amplifier U3 may be selected as opto-isolator CNY51, manufactured by the Semiconductor Products Department, General Electric Company, Auburn, New York.

Feedback voltage  $V_f$  is coupled to a noninverting input terminal of an amplifier U1 to develop at the output of amplifier U1 a frequency control voltage  $V_{c1}$ . The inverting input terminal of amplifier U1 is grounded via a resistor R17. Linear operation of amplifier U1 is provided by feeding back voltage  $V_{c1}$  to the inverting input terminal via resistors R18 and R19. The gain of amplifier U1 is determined by the value of this feedback resistance.

During normal regulator operation, frequency control voltage  $V_{c1}$  is applied to a frequency control input pin 4 of oscillator 41 via a resistor R20 and a pass-through diode D4. The frequency control voltage  $V_{c1}$  that is developed across a resistor R21 coupled to frequency control pin 4, varies in accordance with feedback frequency control voltage  $V_{c1}$ .

FIGURE 2 illustrates typical resonant transfer characteristic curves associated with the operation of resonant regulator 20. Curve 31, for example, illustrates a transfer characteristic for a given level of unregulated voltage  $V_{in}$  when power transformer T1 is loaded by an equivalent resistance  $R_L = R_{L1}$ .

Frequency control circuit 50 controls operating frequency  $f$  so as to establish an operating point  $P_1$  on curve 31 at a frequency  $f_1$  that regulates output supply voltage V1 to its desired level. From the location of operating point  $P_1$  on the positive slope

of transfer characteristic curve 31, one notes that frequency control circuit 50 is designed to regulate at frequencies below, or to the left side of, resonance frequency  $f_{res}$ .

Assume now that the loading on power transformer T1 increases from an equivalent load resistance  $R_{L1}$  to a smaller resistance  $R_{L2}$ . The resonant transfer characteristic curve of resonant circuit 10 for the new operating condition is curve 32 of FIGURE 2. The resonance frequency for curve 32 will be very close to that of resonance frequency  $f_{res}$  of curve 31. Due, however, to the increased loading on resonant circuit 10, the peak of curve 32 is lower than that of curve 31, and the slope of the curve on either side of resonance is less steep.

If frequency control circuit 50 were unable to respond to the increased loading, and the operating frequency were to remain at frequency  $f_1$ , the new operating point  $P'$  would be at a point on curve 32 that results in decreased amplitude for sinewave input voltage  $V_0$ , and decreased levels for supply voltages V1-V3. Frequency control circuit 50, however, will respond to the tendency of supply voltage V1 to decrease under increased loading by changing the operating frequency to a higher frequency  $f=f_2$ . The higher operating frequency establishes a new operating point  $P_2$  on curve 32 that restores the voltage level V1 to its correct, regulated level.

Frequency control circuit 50 operates in the following manner to, for example, increase the operating frequency as increased loading attempts to decrease supply voltage V1. The decrease in supply voltage V1, being directly coupled to the emitter of transistor Q1 via zener diode Z1, while being only proportionally coupled to the base via divider R1-R4, produces a decrease in transistor conduction. The decrease in conduction of transistor Q1 produces a decrease in feedback voltage  $V_f$  that is amplified by amplifier U1 to produce a decrease in frequency control voltage  $V_{c1}$ . The decrease in frequency control voltage  $V_{c1}$  is passed through diode D4 as a decrease in oscillator frequency control voltage  $V_{c1}$  developed at frequency control pin 4 of the oscillator.

Oscillator 41 may be selected as Precision Oscillator XR-2209, manufactured by EXAR Integrated Systems, Inc., Sunnyvale, California. Oscillator 41 is designed to respond to a decrease in frequency control voltage  $V_{c1}$  in a way that increases the oscillator frequency. Thus, in response to a decrease in supply voltage V1, the operating frequency of resonant circuit 10 increases, in accordance with the gain of the negative feedback loop provided by control circuit 50. This establishes the new operating point  $P_2$  on curve 32 of FIGURE 2 at the higher frequency  $f=f_2$ , so as to restore the supply voltages to their regulated levels.

It may be desirable to design resonant regulator 20 to have a normal operating frequency range that closely approaches the resonance frequency of resonant circuit 10 at the extremes of the operating range. Such a design choice insures that the regulator operates on the relatively steep portion of the resonant transfer characteristic curve, thereby providing good loop response and a relatively wide range of regulation.

Due, however, to circuit tolerances, the operating point of the regulator on a given transfer characteristic curve may be so close to the resonance frequency that frequency control circuit 50 will attempt to locate the operating point on the negative slope of, for example, curve 32. Should a situation arise where the operating frequency passes through the resonance frequency regulation is completely lost, because frequency control circuit 50 will now operate in a positive feedback mode.

For example, control circuit 50 will respond to a decrease in supply voltage  $V_1$  by increasing rather than decreasing the operating frequency, which produces a further decrease in supply voltage.

Embodying an aspect of the invention, resonant regulator 20 includes a frequency limiting circuit 60 that prevents the operating frequency from passing through resonance. When the operating frequency is near but below resonance, the AC voltage across capacitor  $C_0$  is greater than the AC voltage across inductor  $L_0$ . When the operating frequency slightly exceeds resonance, the AC voltage across inductor  $L_0$  is greater than the AC voltage across capacitor  $C_0$ . At resonance, the AC voltages across capacitor  $C_0$  and inductor  $L_0$  are equal. In frequency limiting circuit 60, the voltage developed by inductive element  $L_0$  of resonant circuit 10 is sensed by a secondary winding  $W_s$  magnetically coupled to inductor  $L_0$ .

Frequency limiting circuit 60 also senses the amplitude of voltage  $V_0$  developed across capacitive element  $C_0$  of resonant circuit 10. The capacitive voltage is sensed by a secondary winding  $W_2$  of transformer  $T_1$  that is tightly coupled with primary winding  $W_1$ . The voltage  $V_{CAG}$  across winding  $W_2$  is a transformed voltage representative of capacitive voltage  $V_0$ . Without regulation, the AC voltage across capacitor  $C_0$  decreases with increasing operating frequency. However, the amplitude of voltage  $V_{CAG}$  tends to remain unchanged under normal operating conditions due to the regulation provided by resonant regulator 20.

Capacitive voltage  $V_{CAG}$  is lowpass filtered by a resistor  $R_5$  and a capacitor  $C_5$ , rectified by a diode  $D_1$  to charge a capacitor  $C_8$  that develops a positive DC sense voltage  $+V_C$ , having a magnitude that is in accordance with the amplitude of voltage  $V_{CAG}$ . Inductive voltage  $V_{LAC}$  is lowpass filtered by a resistor  $R_6$  and a capacitor  $C_6$ , rectified by a

diode  $D_2$  to charge a capacitor  $C_9$  that develops a negative DC sense voltage  $-V_L$  having a magnitude that is in accordance with the amplitude of voltage  $V_{LAC}$ .

Capacitive sense voltage  $+V_C$  and inductive sense voltage  $-V_L$  are algebraically summed via respective resistors  $R_9$  and  $R_{10}$  to develop a difference voltage  $V_{diff}$  across a resistor  $R_{11}$  coupled to a summing junction terminal 34. Voltage  $V_{diff}$  is therefore related to the difference in magnitudes between the capacitive sense voltage and the inductive sense voltage, or  $V_{diff} \propto (V_C - V_L)$ .

Voltage  $V_{diff}$  is applied to the inverting input terminal of an amplifier  $U_2$  having a noninverting input terminal that is grounded. The output of amplifier  $U_2$  is coupled to frequency control pin 4 of oscillator 41 via a resistor  $R_{15}$  and a diode  $D_3$ . Negative feedback for amplifier  $U_2$  is provided by resistors  $R_{13}$  and  $R_{14}$  series coupled between the output terminal and the inverting input terminal. Amplifiers  $U_1$  and  $U_2$  may each be selected as CA3140, manufactured by the Solid State Division of RCA Corporation, Somerville, New Jersey.

When the AC voltages across inductor  $L_0$  and capacitor  $C_0$  are equal, resonant circuit 10 is operating at its resonant frequency. The embodiment provides an arrangement for limiting the operating frequency to a predetermined amount below resonance by limiting the increase in operating frequency in response to a predetermined minimum difference between the voltages across inductor  $L_0$  and capacitor  $C_0$ . Since such voltage difference does not decrease beyond its predetermined minimum value, the resonant frequency of resonant circuit 10 is never reached.

By properly selecting the number of turns for windings  $W_2$  and  $W_s$ , the magnitude of inductive sense voltage  $V_L$  is maintained smaller than the magnitude of the capacitance sense voltage  $V_C$ , within the normal operating frequency range below resonance. The difference voltage  $V_{diff}$  is a positive value.

A positive voltage  $V_{diff}$ , when applied to the inverting input terminal of amplifier  $U_2$ , produces cutoff of amplifier  $U_2$ . Since the voltage at frequency control pin 4 is positive during normal operation of resonant regulator 20, diode  $D_3$  is reverse biased and blocks the voltage at the output of amplifier  $U_2$  from passing through to pin 4 and affecting the normal operation of the negative feedback loop formed by frequency control circuit 50.

As the operating frequency of resonant regulator 20 is increased and moves the operating point towards resonance on, for example, characteristic curve 32 of FIGURE 2, an operating point  $P_{m2}$  is reached at a frequency  $f_{m2}$  where the magnitude of inductive sense voltage  $-V_L$  has increased sufficiently to reverse the polarity of voltage  $V_{diff}$  and

produces a negative value for the voltage. Control voltage  $V_{c2}$ , developed at the output of amplifier U2, becomes a positive-valued voltage.

The feedback resistance of amplifier U2 is selected to be much greater than the feedback resistance of amplifier U1, illustratively 10 or more times greater. The voltage gain of amplifier U2 is therefore much greater than the voltage gain of amplifier U1.

When voltage  $V_{diff}$  becomes negative at frequency  $f_{m2}$ , any slight further increase in frequency will produce a relatively large increase in positive control voltage  $V_{c2}$ . Diode D3 becomes forward biased, to pass through voltage  $V_{c2}$  to frequency control pin 4 of oscillator 41. Diode D4 becomes reversed biased and blocks voltage  $V_{c1}$  from being applied to frequency control pin 4. Oscillator frequency control voltage  $V_{co}$  is now controlled exclusively by control voltage  $V_{c2}$ . The negative feedback loop provided by frequency control circuit 50 becomes disabled, and any attempt to further increase the operating frequency will be ineffective due to the higher gain of amplifier U2 relative to that of amplifier U1. Furthermore, for frequency control circuit 50 to increase the operating frequency, it must decrease frequency control voltage  $V_{c1}$ . This would further increase the reverse biasing potential across diode D4. In these ways, frequency limiting circuit 60 prevents the resonant regulator operating frequency from increasing beyond frequency  $f_{m2}$ .

Frequency limiting circuit 60 automatically holds the upper frequency limit of operation to a given design guard band below the resonance frequency, even though the resonance frequency itself may vary due to component tolerances, temperature, and aging effects. The relative magnitudes of the AC voltages across inductive element  $L_0$  and capacitive element  $C_0$  of resonant circuit 10 tend to inversely track each other near resonance. Voltage  $V_{diff}$ , which is indicative of the closeness of the operating frequency to resonance, is related to the difference in magnitudes of the inductive and capacitive voltages. Voltage  $V_{diff}$  is a monotonic function in the region of interest to either side of resonance on the transfer characteristic curve, with voltage  $V_{diff}$  reversing polarity as the frequency closes to near resonance.

By designing the reversal of polarity to occur before resonance is reached, voltage limiting circuit 60 may be activated at an amount below resonance that is relatively independent of tolerances, temperature and component aging which would change the resonant frequency itself. Thus, when the effects of tolerance, temperature and component aging produce a different resonant transfer characteristic curve having a different resonance frequency  $f_{res}$ , in curve 32' of FIGURE 2, frequency

limit circuit 60 still provides a limiting action. The regulator operating point and frequency will be driven to just below resonance to, for example, point  $P'_{m2}$ , at a high-limit frequency  $f_{m2}$ . Furthermore, since voltage  $V_{diff}$  is monotonic through resonance, voltage  $V_{diff}$  is able to limit the operating frequency without experiencing a reversal from negative feedback operation to positive feedback operation.

Frequency limiting circuit 60 advantageously provides frequency limiting under short-circuit load conditions. Should a short-circuit load be developed by power transformer T1, input voltage  $V_0$  and capacitive sense voltage  $+V_C$  will be absent or much reduced in amplitude, while inductive sense voltage  $-V_L$  will be substantially increased in amplitude. The difference voltage  $V_{diff}$  will become negative and drive control voltage  $V_{co}$  to a relatively large value that blocks diode D4 and drives the operating frequency below resonance.

By way of illustration only, the following values may be chosen for inductor  $L_0$  and transformer T1, assuming negligible leakage. Inductor  $L_0$  has an inductance of 440 microhenry and a ratio of turns for  $W_2$  to turns for  $L_0$  of 7:67. Transformer T1 develops an effective inductance across capacitor  $C_0$  of 800 microhenry and a ratio of turns  $W2$  to turns  $W1$  of 5:49.

Illustrative operating frequencies for nominal component values are the following: an operating frequency of 56.4 kilohertz at a high AC mains voltage of 270 VAC, RMS and at an equivalent load of 100 watts; an operating frequency of 67 kilohertz at a low AC mains voltage of 180 VAC, RMS and at an equivalent load of 100 watts. The resonance frequency is approximately 77 kilohertz, with the high-limit frequency being approximately 75.5 kilohertz.

#### Claims

1. A resonant regulator power supply, comprising:
  - a source (S1,S2) of alternating input voltage, controllable in operating frequency;
  - a resonant circuit (10) coupled to and excited by said source and having associated therewith a resonance frequency, said resonant circuit including an inductive element ( $L_0$ ) and a capacitive element ( $C_0$ );
  - means (W3) coupled to said resonant circuit (10) for generating an output supply voltage;
  - a control circuit (50) coupled to said source (S1,S2) and responsive to said output supply voltage for varying said operating frequency in a negative feedback loop to regulate said output supply voltage; and
  - a frequency limiting circuit (60) coupled to



produces a negative value for the voltage. Control voltage  $V_{c2}$ , developed at the output of amplifier U2, becomes a positive-valued voltage.

The feedback resistance of amplifier U2 is selected to be much greater than the feedback resistance of amplifier U1, illustratively 10 or more times greater. The voltage gain of amplifier U2 is therefore much greater than the voltage gain of amplifier U1.

When voltage  $V_{diff}$  becomes negative at frequency  $f_{m2}$ , any slight further increase in frequency will produce a relatively large increase in positive control voltage  $V_{c2}$ . Diode D3 becomes forward biased, to pass through voltage  $V_{c2}$  to frequency control pin 4 of oscillator 41. Diode D4 becomes reversed biased and blocks voltage  $V_{c1}$  from being applied to frequency control pin 4. Oscillator frequency control voltage  $V_{co}$  is now controlled exclusively by control voltage  $V_{c2}$ . The negative feedback loop provided by frequency control circuit 50 becomes disabled, and any attempt to further increase the operating frequency will be ineffective due to the higher gain of amplifier U2 relative to that of amplifier U1. Furthermore, for frequency control circuit 50 to increase the operating frequency, it must decrease frequency control voltage  $V_{c1}$ . This would further increase the reverse biasing potential across diode D4. In these ways, frequency limiting circuit 60 prevents the resonant regulator operating frequency from increasing beyond frequency  $f_{m2}$ .

Frequency limiting circuit 60 automatically holds the upper frequency limit of operation to a given design guard band below the resonance frequency, even though the resonance frequency itself may vary due to component tolerances, temperature, and aging effects. The relative magnitudes of the AC voltages across inductive element  $L_0$  and capacitive element  $C_0$  of resonant circuit 10 tend to inversely track each other near resonance. Voltage  $V_{diff}$ , which is indicative of the closeness of the operating frequency to resonance, is related to the difference in magnitudes of the inductive and capacitive voltages. Voltage  $V_{diff}$  is a monotonic function in the region of interest to either side of resonance on the transfer characteristic curve, with voltage  $V_{diff}$  reversing polarity as the frequency closes to near resonance.

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Illustrative operating frequencies for nominal component values are the following: an operating frequency of 56.4 kilohertz at a high AC mains voltage of 270 VAC, RMS and at an equivalent load of 100 watts; an operating frequency of 67 kilohertz at a low AC mains voltage of 180 VAC, RMS and at an equivalent load of 100 watts. The resonance frequency is approximately 77 kilohertz, with the high-limit frequency being approximately 75.5 kilohertz.

#### Claims

1. A resonant regulator power supply, comprising:
  - a source (S1,S2) of alternating input voltage, controllable in operating frequency;
  - a resonant circuit (10) coupled to and excited by said source and having associated therewith a resonance frequency, said resonant circuit including an inductive element ( $L_0$ ) and a capacitive element ( $C_0$ );
  - means (W3) coupled to said resonant circuit (10) for generating an output supply voltage;
  - a control circuit (50) coupled to said source (S1,S2) and responsive to said output supply voltage for varying said operating frequency in a negative feedback loop to regulate said output supply voltage; and
  - a frequency limiting circuit (60) coupled to



said source (S1,S2) for preventing the operating frequency from passing through the resonance frequency;

characterized by first sense voltage developing means ( $W_s$ ) coupling the frequency limiting circuit (60) to the resonant circuit (10) and developing a first sense voltage ( $V_{LAC}$ ) representative of an inductive voltage developed by said inductive element ( $L_0$ ) and second sense voltage developing means ( $W_2$ ) for developing a second sense voltage ( $V_{CAC}$ ) representative of a capacitive voltage developed by said capacitive element ( $C_0$ ), the frequency limiting circuit (60) being responsive to said first ( $V_{LAG}$ ) and second ( $V_{CAC}$ ) sense voltages for preventing said operating frequency from passing through said resonance frequency.

2. A power supply according to claim 1 wherein normal operation is in a range of said operating frequency that is below said resonance frequency.
3. A power supply according to claim 1 or claim 2 wherein said second sense voltage developing means includes a transformer (T1) having a first winding (W1) coupled to said capacitive element ( $C_0$ ) and having a second winding (W2) for developing said second sense voltage.
4. A power supply according to claim 1 or claim 2 wherein said output supply voltage generating means includes a power transformer (T1) having a first winding (W1) coupled to said capacitive element ( $C_0$ ), a second winding (W3) for generating said output supply voltage, and a third winding (W2) for developing said second sense voltage.
5. A power supply according to any of claims 1 to 4 wherein said first sense voltage developing means comprises a sense winding ( $W_s$ ) magnetically coupled to said inductive element ( $L_0$ ).
6. A power supply according to any of claims 1 to 5 wherein said frequency limiting circuit (60) includes means ( $R_9, R_{10}, R_{11}$ ) responsive to said first and second sense voltages for developing a third sense voltage ( $V_{diff}$ ) indicative of a difference between said inductive ( $V_{LAC}$ ) and capacitive ( $V_{CAC}$ ) voltages.
7. A power supply according to claim 6 wherein said third sense voltage ( $V_{diff}$ ) comprises the algebraic sum of said first ( $V_C$ ) and second ( $V_L$ ) sense voltages such that a magnitude of said

third sense voltage ( $V_{diff}$ ) is indicative of the closeness of said operating frequency to said resonance frequency.

8. A power supply according to claim 7 wherein a first polarity of said third sense voltage ( $V_{diff}$ ) is indicative of said operating frequency being one of a below-resonance frequency and an above-resonance frequency.
9. A resonant regulator power supply according to claim 1, 2, 3, 4 or 5, wherein the control circuit (50) includes a first amplifier (U1) for amplifying a negative feedback voltage representative of said output supply voltage; and the limiting circuit (60) includes a second amplifier (U2) for amplifying a frequency sense voltage ( $V_{diff}$ ), derived from the first and second sense voltages, that is indicative of the closeness of said operating frequency to said resonance frequency.
10. A power supply according to claim 9 wherein the second amplifier (U2) has a gain that is substantially greater than that of said first amplifier.
11. A power supply according to claim 9 or 10, further comprising means (D3,D4) for combining outputs of said first (U1) and second (U2) amplifiers, wherein a magnitude of the output of said first amplifier (U1) tends to vary in a given sense when said operating frequency varies in a first direction, whereas a magnitude of the output of said second amplifier (U2) tends to vary in an opposing sense.
12. A power supply according to claim 9, 10 or 11 further comprising a switching arrangement (D3,D4) coupled to the two amplifiers (U1,U2) for preventing said source (S1,S2) of alternating input voltage from responding to said frequency sense voltage when said operating frequency is within a first range of frequencies on one side of said resonance frequency and for preventing said source from responding to said negative feedback voltage when said operating frequency is within a given limit of said resonance frequency.
13. A power supply according to claim 12 wherein said switching arrangement comprises first (D4) and second (D3) diodes series coupled with respective outputs of said first (U1) and second (U2) amplifiers, said frequency sense



voltage blocking conduction of said first diode (D4) when said operating frequency approaches said resonance frequency to within said given limit.

### Revendications

1. Source d'alimentation de puissance à régulateur résonnant comprenant :
  - une source (S1, S2) de tension d'entrée alternative, dont la fréquence de fonctionnement peut être commandée ;
  - un circuit résonnant (10) couplé à, et excité par ladite source et auquel est associée une fréquence de résonance, ledit circuit résonnant comportant un élément inductif ( $L_0$ ) et un élément capacitif ( $C_0$ ) ;
  - des moyens (W3) couplés audit circuit résonnant (10) pour générer une tension d'alimentation de sortie ;
  - un circuit de commande (50) couplé à ladite source (S1, S2) et agissant en réponse à ladite tension d'alimentation de sortie pour faire varier ladite fréquence de fonctionnement dans une boucle de réaction négative pour réguler ladite tension d'alimentation de sortie et
  - un circuit de limitation de fréquence (60) couplé à ladite source (S1, S2) pour s'opposer au passage de la fréquence de fonctionnement par la fréquence de résonance ;
 caractérisé par des moyens développant une tension de détection ( $V_S$ ), couplant le circuit de limitation de fréquence (60) au circuit résonnant (10) et développant une première tension de détection ( $V_{LAC}$ ) représentant une tension inductive développée par ledit élément inductif ( $L_0$ ) et des seconds moyens de développement de tension de détection (W2) pour développer une seconde tension de détection ( $V_{CAC}$ ) représentative d'une tension capacitive développée par ledit élément capacitif ( $C_0$ ), le circuit de limitation de fréquence (60) agissant en réponse auxdites première ( $V_{LAC}$ ) et seconde ( $V_{CAC}$ ) tensions de détection pour empêcher ladite fréquence de fonctionnement de passer par ladite fréquence de résonance.
2. Source d'alimentation de puissance selon la revendication 1 dans laquelle le fonctionnement normal se situe dans une gamme de ladite fréquence de fonctionnement qui est en dessous de ladite fréquence de résonance.
3. Source d'alimentation de puissance selon la revendication 1 ou la revendication 2 dans

laquelle lesdits seconds moyens de développement de tension de détection comprennent un transformateur (T1) ayant un premier enroulement (W1) couplé audit élément capacitif ( $C_0$ ) et ayant un second enroulement (W2) pour développer ladite seconde tension de détection.

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4. Source d'alimentation selon la revendication 1 ou 2 dans laquelle lesdits moyens générant la tension d'alimentation de sortie comportent un transformateur de puissance (T1) ayant un premier enroulement (W1) couplé audit élément capacitif ( $C_0$ ), un second enroulement (W3) pour générer ladite tension d'alimentation de sortie et un troisième enroulement (W2) pour développer ladite seconde tension de détection.

5. Source d'alimentation de puissance selon l'une des revendications 1 à 4 dans laquelle lesdits premiers moyens de développement de tension de détection comprennent un enroulement de détection ( $W_S$ ) couplé magnétiquement audit élément inductif ( $L_0$ ).

6. Source d'alimentation de puissance selon l'une des revendications 1 à 5 dans laquelle ledit circuit de limitation de fréquence (60) comprend des moyens (R9, R10, R11) agissant en réponse auxdites première et seconde tensions de détection pour développer une troisième tension de détection ( $V_{DIF}$ ) indiquant une différence entre lesdites tensions inductives ( $V_{LAC}$ ) et capacitive ( $V_{CAC}$ ).

7. Source d'alimentation de puissance selon la revendication 6 dans laquelle ladite troisième tension de détection ( $V_{DIF}$ ) comprend la somme algébrique de ladite première ( $V_C$ ) et de ladite seconde ( $V_L$ ) tensions de détection de façon qu'une valeur de ladite troisième tension de détection ( $V_{DIF}$ ) soit une indication de la proximité de ladite fréquence de fonctionnement, de ladite fréquence de résonance.

8. Source d'alimentation de puissance selon la revendication 7 dans laquelle une première polarité de ladite troisième tension de détection ( $V_{DIF}$ ) est une indication selon laquelle ladite fréquence de fonctionnement est l'une des fréquences situées au-dessus de la résonance et en dessous de la résonance.

9. Source d'alimentation de puissance à régulateur résonnant selon la revendication 1,2,3,4 ou 5 dans laquelle
  - le circuit de commande (50) comprend



un premier amplificateur (U1) pour amplifier une tension de réaction négative représentant ladite tension d'alimentation de sortie et

- le circuit de limitation (60) comporte un second amplificateur (U2) pour amplifier une tension de détection de fréquence ( $V_{diff}$ ), dérivée de la première et de la seconde tensions de détection, qui est une indication de la proximité de ladite fréquence de fonctionnement, de la fréquence de résonance.

10. Source d'alimentation de puissance selon la revendication 9, dans laquelle le second amplificateur (U2) possède un gain qui est sensiblement supérieur à celui dudit premier amplificateur.

1. Source d'alimentation de puissance selon la revendication 9 ou 10 comprenant en outre :

des moyens (D3, D4) pour combiner des sorties desdits premier (U1) et second (U2) amplificateurs, dans lesquels une valeur de la sortie dudit premier amplificateur (U1) tend à varier dans un sens donné lorsque ladite fréquence de fonctionnement varie dans une première direction alors qu'une valeur de la sortie dudit second amplificateur (U2) tend à varier dans un sens opposé.

12. Source d'alimentation de puissance selon la revendication 9, 10 ou 11 comprenant en outre :

- un système de commutation (D3, D4) couplé aux deux amplificateurs (U1, U2) pour empêcher ladite source (S1, S2) de tension d'entrée alternative d'agir en réponse à ladite tension de détection de fréquence, lorsque ladite fréquence de fonctionnement est située à l'intérieur d'une première gamme de fréquences sur un côté de ladite fréquence de résonance et pour s'opposer à ce que ladite source agisse en réponse à ladite tension de réaction négative lorsque ladite fréquence de fonctionnement se situe dans une limite donnée de ladite fréquence de résonance.

13. Source d'alimentation de puissance selon la revendication 12 dans laquelle le système de commutation comprend des première (D4) et seconde (D3) diodes couplées en série avec les sorties respectives desdits premier (U1) et second (U2) amplificateurs, ladite tension de détection de fréquence bloquant la conduction de ladite première diode (D4) lorsque ladite

fréquence de fonctionnement approche de la fréquence de résonance jusqu'à l'intérieur de ladite limite donnée.

## 5 Patentansprüche

1. Resonanzregler-Netzteil, welches aufweist:  
eine Quelle (S1,S2) von Eingangs-Wechselspannung, die in ihrer Betriebsfrequenz steuerbar/regelbar ist;  
einen Resonanzkreis (10), der mit der Quelle (S1,S2) gekoppelt ist und von ihr angeregt wird und mit dem eine Resonanzfrequenz assoziiert ist, wobei die Resonanzschaltung (10) ein induktives Element ( $L_0$ ) und ein kapazitives Element ( $C_0$ ) aufweist;  
eine Einrichtung (W3), die mit dem Resonanzkreis (10) zur Erzeugung einer Ausgangs-Versorgungsspannung gekoppelt ist;  
eine Steuerschaltung (50), die mit der Quelle (S1,S2) gekoppelt ist und abhängig von der Ausgangs-Versorgungsspannung die Betriebsfrequenz in einer negativen Rückkopplungsschleife variiert zum Regeln der Ausgangs-Versorgungsspannung; und  
eine Frequenz-Begrenzerschaltung (60), die mit der Quelle (S1,S2) gekoppelt ist, so daß vermieden wird, daß die Betriebsfrequenz die Resonanzfrequenz passiert;  
**gekennzeichnet durch**  
eine erste Meßspannungs-Bildungseinrichtung ( $W_S$ ), welche die Frequenz-Begrenzerschaltung (60) mit dem Resonanzkreis (10) koppelt und die eine erste Meßspannung ( $V_{LAC}$ ) bildet, die für eine an dem induktiven Element ( $L_0$ ) gebildete induktive Spannung repräsentativ ist und eine zweite Meßspannungs-Bildungseinrichtung ( $W_2$ ) zur Bildung einer zweiten Meßspannung ( $V_{CAC}$ ), die für eine an dem kapazitiven Element ( $C_0$ ) gebildete kapazitive Spannung repräsentativ ist, wobei die Frequenz-Begrenzerschaltung (60) abhängig von der ersten ( $V_{LAC}$ ) und von der zweiten ( $V_{CAC}$ ) Meßspannung vermeidet, daß die Betriebsfrequenz die Resonanzfrequenz passiert.
2. Netzteil nach Anspruch 1, bei dem der Normalbetrieb in einem Bereich der Betriebsfrequenz liegt, der unterhalb der Resonanzfrequenz liegt.
3. Netzteil nach Anspruch 1 oder 2, bei dem die zweite Meßspannungs-Bildungseinrichtung ( $W_2, T1$ ) einen Übertrager (T1) aufweist, der eine erste - mit dem kapazitiven Element ( $C_0$ ) gekoppelte - Wicklung (W1) und eine zweite Wicklung (W2) zur Bildung der zweiten Meß-



spannung hat.

4. Netzteil nach Anspruch 1 oder 2, bei dem die Ausgangs- Versorgungsspannungserzeugungseinrichtung (W3,T1) einen Leistungsübertrager (T1) aufweist, der eine erste Wicklung (W1), die mit dem kapazitiven Element ( $C_0$ ) gekoppelt ist, eine zweite Wicklung (W3) zur Erzeugung der Ausgangs-Versorgungsspannung und eine dritte Wicklung (W2) hat zur Bildung der zweiten Meßspannung ( $V_{CAC}$ ).
5. Netzteil nach einem oder mehreren der Ansprüche 1 bis 4, bei dem die erste Meßspannungs-Bildungseinrichtung eine Meßwicklung ( $W_S$ ) aufweist, die mit dem induktiven Element ( $L_0$ ) magnetisch gekoppelt ist.
6. Netzteil nach einem oder mehreren der Ansprüche 1 bis 5, bei dem die Frequenz-Begrenzerschaltung (60) eine Einrichtung (R9,R10,R11) aufweist, die abhängig von der ersten und zweiten Meßspannung eine dritte Meßspannung ( $V_{diff}$ ) bildet, die eine Differenz zwischen der induktiven ( $V_{LAG}$ ) und der kapazitiven ( $V_{CAC}$ ) Spannung anzeigt.
7. Netzteil nach Anspruch 6, bei dem die dritte Meßspannung ( $V_{diff}$ ) die algebraische Summe der ersten ( $V_C$ ) und zweiten ( $V_L$ ) Meßspannung aufweist, so daß die Größe der dritten Meßspannung ( $V_{diff}$ ) die Nähe der Betriebsfrequenz zu der Resonanzfrequenz anzeigt.
8. Netzteil nach Anspruch 7, bei dem eine erste Polarität der dritten Meßspannung ( $V_{diff}$ ) die Betriebsfrequenz als eine unterhalb oder oberhalb der Resonanzfrequenz befindliche Frequenz anzeigt.
9. Netzteil nach Anspruch 1, 2, 3, 4 oder 5, bei dem die Steuerschaltung (50) einen ersten Verstärker (U1) zum Verstärken der negativen Rückkopplungsspannung, welche die Ausgangs-Versorgungsspannung repräsentiert; und die Frequenz-Begrenzerschaltung (60) einen zweiten Verstärker (U2) aufweist, zum Verstärken einer Frequenz-Meßspannung ( $V_{diff}$ ), die von der ersten und zweiten Meßspannung ( $V_C$ ,  $V_L$ ) abgeleitet ist und welche die Nähe der Betriebsfrequenz zu der Resonanzfrequenz anzeigt.
10. Netzteil nach Anspruch 9, bei dem der zweite Verstärker (U2) eine Verstärkung aufweist, die wesentlich größer als diejeniges

des ersten Verstärkers (U1) ist.

11. Netzteil nach Anspruch 9 oder 10, bei dem eine Einrichtung (D3,D4) vorgesehen ist zum Verbinden der Ausgangssignale des ersten und zweiten Verstärkers (U1,U2), in der die Größe des Ausgangssignals des ersten Verstärkers (U1) in einer gegebenen Richtung zu ändern tendiert, wenn sich die Betriebsfrequenz in einer ersten Richtung verändert, wohingegen die Größe der Ausgangsspannung des zweiten Verstärkers (U2) dazu neigt, sich in die entgegengesetzte Richtung zu verändern.
12. Netzteil nach Anspruch 9, 10 oder 11, bei dem eine Schaltungsanordnung (D3,D4) mit den beiden Verstärkern (U1,U2) gekoppelt ist, die vermeidet, daß die Quelle (S1,S2) von Eingangs-Wechselspannung auf die Frequenz-Meßspannung ( $V_{diff}$ ) reagiert, wenn die Betriebsfrequenz in einem ersten Bereich von Frequenzen auf einer Seite der Resonanzfrequenz ist und die vermeidet, daß die Quelle (S1,S2) auf die negative Rückkopplungsspannung reagiert, wenn die Betriebsfrequenz innerhalb eines gegebenen Limits von der Resonanzfrequenz ist.
13. Netzteil nach Anspruch 12, bei dem die Schalteranordnung (D3,D4) eine erste (D4) und eine zweite (D3) Diode aufweist, die mit dem jeweiligen Ausgang des ersten (U1) und zweiten (U2) Verstärkers seriell gekoppelt ist, wobei die Frequenz-Meßspannung die erste Diode (D4) sperrt, wenn die Betriebsfrequenz sich der Resonanzfrequenz in oder an das gegebene Limit annähert.