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United States Patent [19]

Redl

[54] **PWM CONTROLLER FOR RESONANT CONVERTERS**

[75] Inventor: **Richard Redl**, Onnens, Switzerland

[73] Assignee: **Toko, Inc.**, Japan

[21] Appl. No.: **532,476**

[22] Filed: **Sep. 22, 1995**

[51] Int. Cl.^{6} **H02M 3/335**

[52] U.S. Cl. **323/21**; 363/79; 363/97; 323/235

[58] **Field of Search** 363/16, 21, 79, 363/80, 97, 131; 323/235

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,864,480	9/1989	Melcher	363/21
5,387,822	2/1995	Martin-Lopez et al.	323/280
5,532,626	7/1996	Khayat	327/53

OTHER PUBLICATIONS

Kwang–Hwa Liu and Fred C. Lee, "Zero–Voltage Switching Technique in DC/DC Converters," IEEE, 1986, pp. 58–70.

Richard Redl and Bela Molnar, "Class–E Resonant Regulated DC/DC Power Converters: Analysis of Operation, and Experimental Results at 1.5 MHz," IEEE PESC, 1983 Record, pp. 50–60.

N.O. Sokal and A.D. Sokal, "Class E–A New Class of High Efficiency Tuned Single–Ended Switching Power Amplifiers," IEEE Journal of Solid–State Circuits, pp. 168–176, Jun. 1975, vol. SC–10, No. 3.

[57] **ABSTRACT**

A pulse width modulated controller controls a zero-voltage switching resonant power converter or inverter. The on time of the power switch (**110**) of the converter or inverter is varied by an error amplifier (**280**) such that the output voltage of the converter or inverter maintains proportionality to a reference voltage (**290**). The off time is terminated by a switch-voltage detector (**320**) when the voltage across the power switch (**110**) drops below a threshold voltage (**330**) due to the natural resonance of the external resonating capacitor (**120**) and inductors (**130** and **150**). In the first two embodiments of the invention, a single timing capacitor (**260**) is employed both for determining the on time and the off time. In two other embodiments, two timing capacitors (**262** and **264**) are employed for separately determining the maximum allowed off time and the variable on time. A cycle-by-cycle current limit circuit comprising a current sensor (**605**), a comparator (**610**), and an R-S latch (**620**) may be added to the circuits representing each of the embodiments. By incorporating a soft start subcircuit (**775**) and an overlap detector (**710**, **715**, **20**, **725**), protection against overdissipation of the power switch caused by loss of zero-voltage switching can also be implemented. The soft start subcircuit can also be triggered by a voltage detector (**740**, **745**), which monitors the output voltage of the power converter or some other voltage within the system, such as the peak voltage across the power switch (**110**), to effectively implement overvoltage protection.
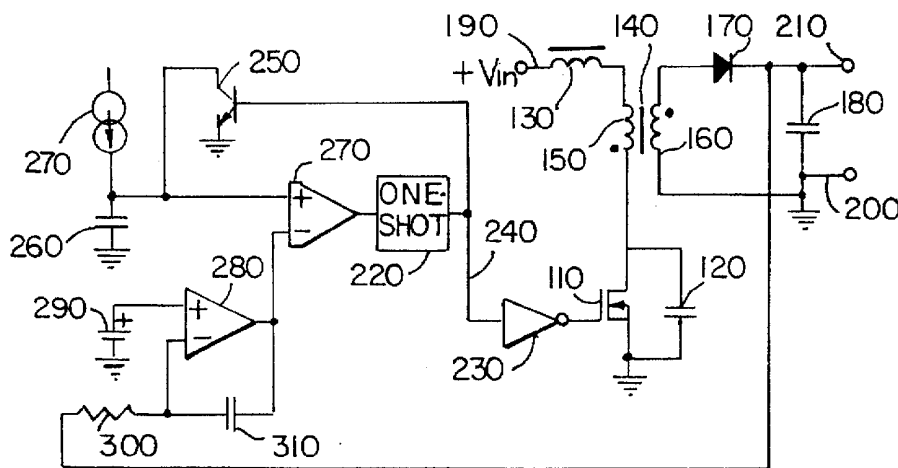
9 Claims, 7 Drawing Sheets
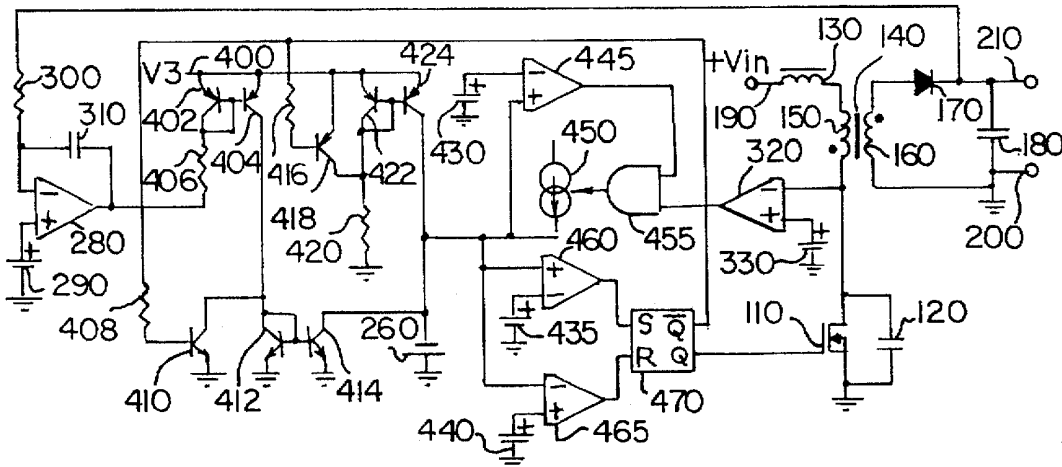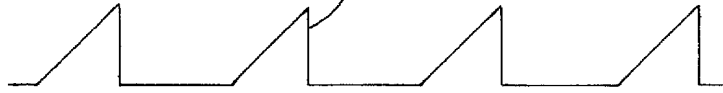
FIG.1
(PRIOR ART)

VOLTAGE ACROSS CAPACITOR 260
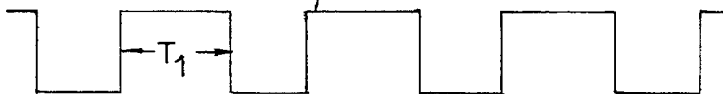
FIG. 2 A
(PRIOR ART)

VOLTAGE AT OUTPUT 240
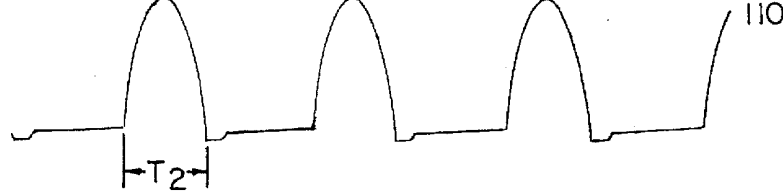
FIG.2B
(PRIOR ART)

VOLTAGE ACROSS POWER SWITCH 110
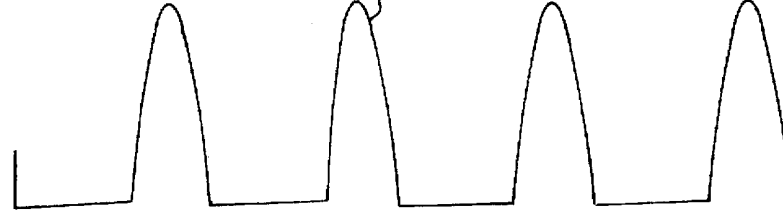
FIG.2C
(PRIOR ART)

VOLTAGE ACROSS POWER SWITCH 110

FIG.3A
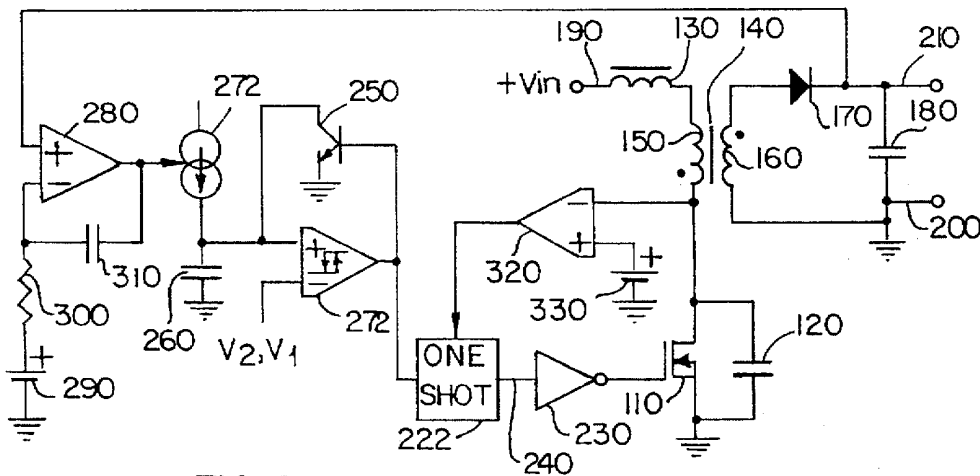(PRIOR ART)

CURRENT IN POWER SWITCH 110

FIG.3B
(PRIOR ART)

VOLTAGE ACROSS POWER SWITCH 110
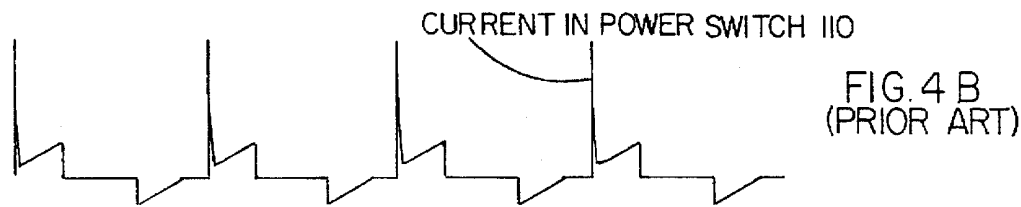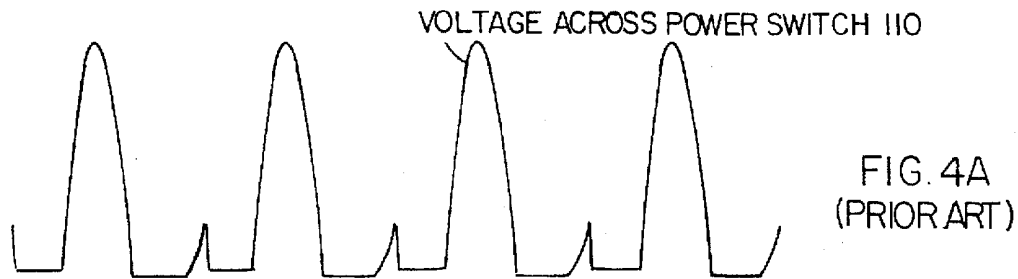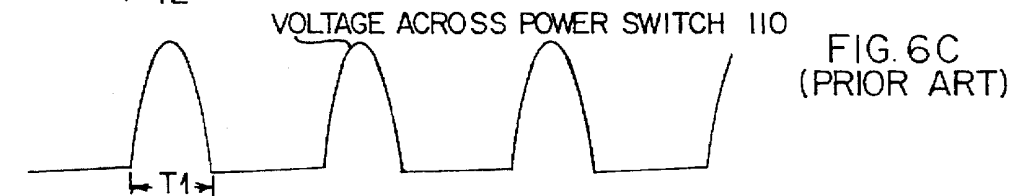
FIG. 4A
(PRIOR ART)

CURRENT IN POWER SWITCH 110

FIG. 4B
(PRIOR ART)

FIG. 5
(PRIOR ART)

VOLTAGE ACROSS CAPACITOR 260

FIG. 6A
(PRIOR ART)

VOLTAGE AT OUTPUT 240

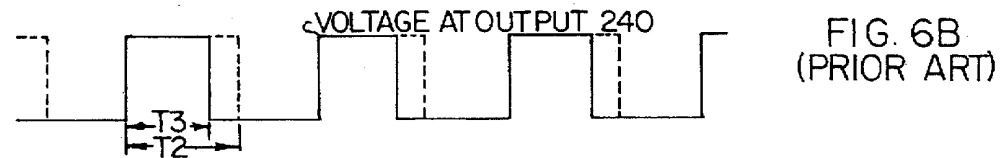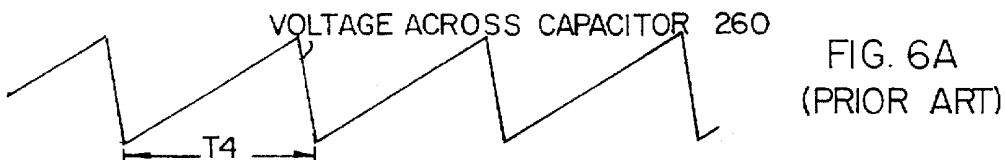FIG. 6B
(PRIOR ART)

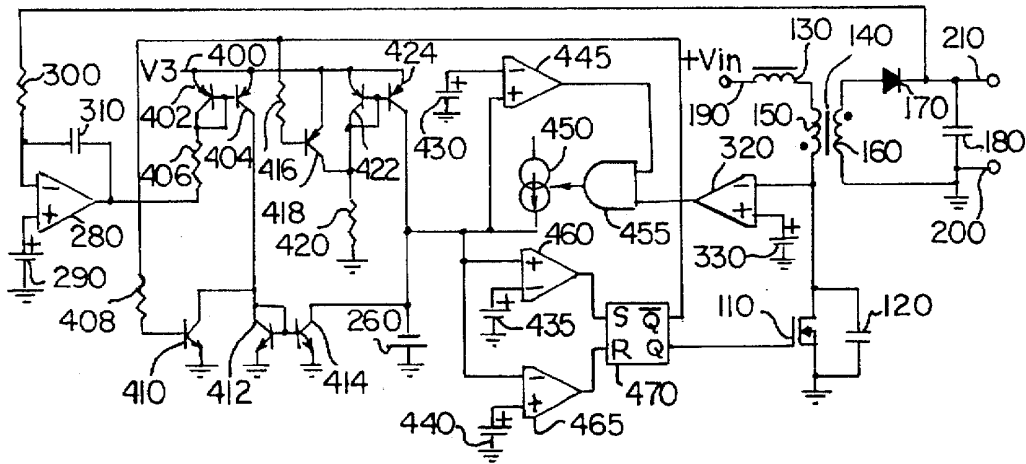VOLTAGE ACROSS POWER SWITCH 110

FIG. 6C
(PRIOR ART)

FIG.7

VOLTAGE ACROSS CAPACITOR 260

FIG. 8A

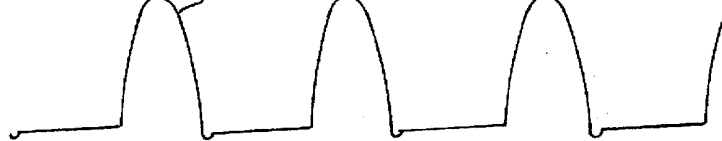VOLTAGE AT Q OUTPUT OF R-S LATCH 470

FIG.8B

VOLTAGE ACROSS POWER SWITCH 110

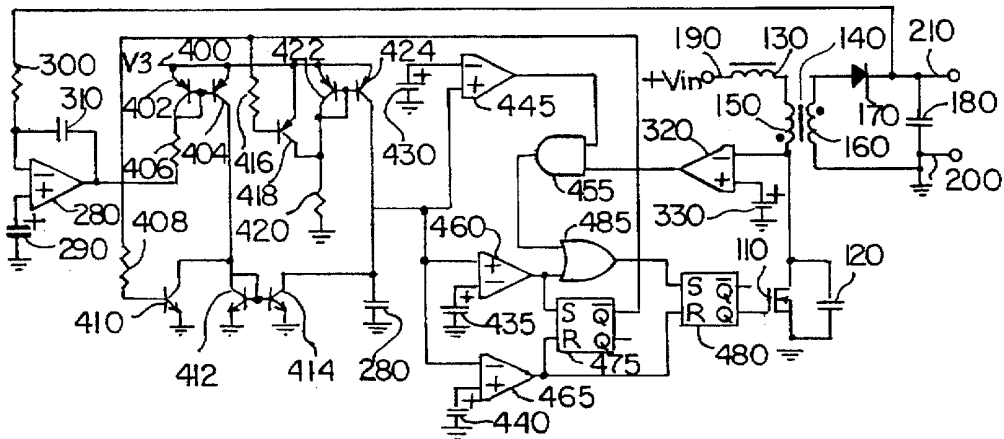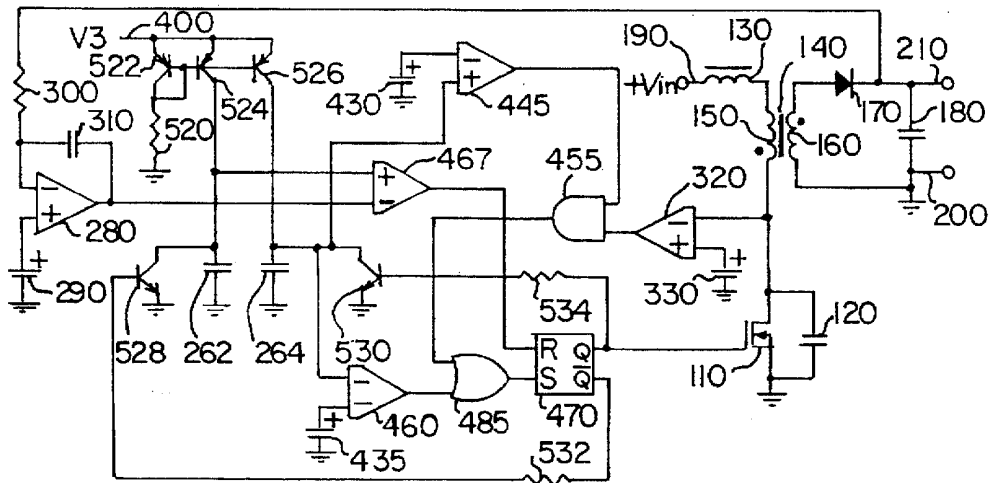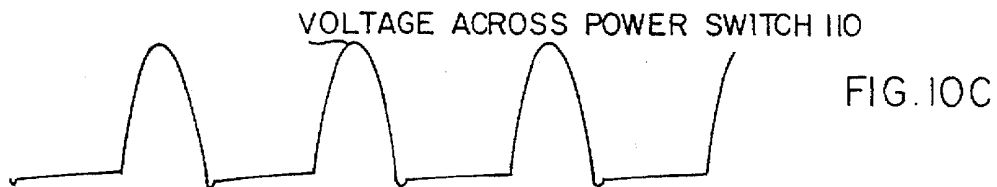FIG. 8C

FIG. 9

VOLTAGE ACROSS CAPACITOR 260   FIG.IOA

VOLTAGE AT Q OUTPUT OF R-S LATCH 480   FIG.IOB

VOLTAGE ACROSS POWER SWITCH 110   FIG.IOC

FIG. II

DOCKET ALARM
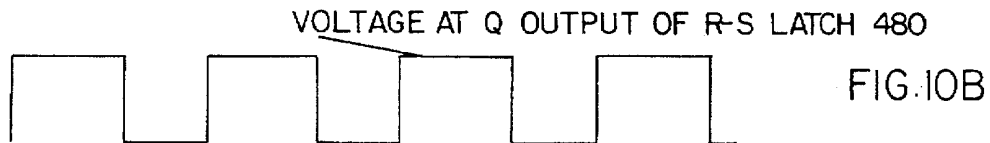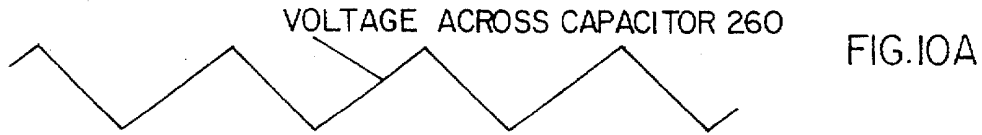
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