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FORM 1
REGULATION 9

COMMONWEALTH OF AUSTRALIA

PATENTS ACT 1952-1973

APPLICATION FOR A PATENT

We HUGHES AIRCRAFT COMPANY

of 7200 Hughes Terrace, Los Angeles, CALIFORNIA 90045-0066, U.S.A.

hereby apply for the grant of a Patent for an invention entitled:

CAPACITIVE COUPLED POWER SUPPLIES

which is described in the accompanying complete specification. This Application is a Convention Application and is based on the Application numbered: 173,223 for a Patent or similar protection made in U.S.A. on 24 March 1988.

Our address for service is:

GRIFFITH HACK & CO.
71 YORK STREET
SYDNEY N.S.W. 2000
AUSTRALIA

DATED this 9th day of March, 1989.

HUGHES AIRCRAFT COMPANY
By their Patent Attorneys

GRIFFITH HACK & CO.

TO: THE COMMISSIONER OF PATENTS
COMMONWEALTH OF AUSTRALIA

APPLICATION ACCEPTED AND AMENDMENTS ALLOWED 14-8-90

8437A:rk

ASSIGNEE - APPLICANT

PD 86055

COMMONWEALTH OF AUSTRALIA

PATENTS ACT 1952 (AS AMENDED)

DECLARATION IN SUPPORT OF AN APPLICATION FOR A PATENT

(Name of applicant) In support of an Application made by: HUGHES AIRCRAFT COMPANY

(Title) for a patent for an invention entitled: CAPACITIVE COUPLED POWER SUPPLIES

(Full name of signatory) I, A. W. Karambelas

(Address of signatory) of 7200 Hughes Terrace
Los Angeles, California 90045-0066
United States of America

do solemnly and sincerely declare as follows:

1. I am authorised by the above mentioned applicant for the patent to make this Declaration on its behalf.

2. The name and address of each actual inventor of the invention is as follows:

(Insert details of inventor/s)

See attached Addendum

(Insert details of assignment, etc.)

and the fact(s) upon which the applicant is entitled to make this application are as follows:

an Assignment by the inventors to the applicant dated February 26, 1988 (McClanahan, Washburn, Gonzalez and Lusher) and March 15, 1988 (Sze)

(Delete paragraphs 3 and 4 for Non-Convention application)

3. The basic application(s) as defined by Section 141 of the Act was(were) made as follows:

Country United States of America on March 24, 1988

in the name(s) Robert F. McClanahan, Robert D. Washburn, Carlos H. Gonzalez,

and in Jerry C. Sze and David M. Lusher on

in the name(s)

and in on

in the name(s)

4. The basic application(s) referred to in the preceding paragraph of this Declaration was(were) the first application(s) made in a Convention country in respect of the invention the subject of this application.

(Place and date of signing)

Declared at Los Angeles, California, U.S.A. this 8th day of May 1989

Signed: A.W. Karambelas

Position: A. W. Karambelas, Staff Vice President

GRIFFITH HASSEL & FRAZER, P.O. BOX 2133, G.P.O., SYDNEY, N.S.W. 2001 AUSTRALIA

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(54) Title
CAPACITIVE COUPLED POWER SUPPLIES

International Patent Classification(s)
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173223	24.03.88	US UNITED STATES OF AMERICA

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(71) Applicant(s)
HUGHES AIRCRAFT COMPANY

(72) Inventor(s)
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(56) Prior Art Documents
US 4412278
US 4393441

(57) Claim

1. A power supply comprising:

means for providing AC power at a frequency greater than one megahertz;

non resonant means responsive to said AC power for providing DC isolation and for providing capacitively coupled AC Power without inductors or resistors; and

a plurality of rectifying means responsive to said capacitively coupled AC power for providing respective DC outputs.

2. The power supply of Claim 1 wherein the non resonant means comprises a plurality of capacitors which are serially connected, and wherein said plurality of rectifying means are connected to respectively associated ones of said capacitors.

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PATENTS ACT 1952 Form 10

COMPLETE SPECIFICATION

FOR OFFICE USE

Short Title:

Int. Cl:

Application Number:
Lodged:

This document contains the amendments made under Section 49 and is correct for printing.

Complete Specification-Lodged:
Accepted:
Lapsed:
Published:

Priority:

Related Art:

TO BE COMPLETED BY APPLICANT

Name of Applicant: HUGHES AIRCRAFT COMPANY

Address of Applicant: 7200 Hughes Terrace, Los Angeles, CALIFORNIA 90045-0066, U.S.A.

Actual Inventor: Robert F. McClanahan; Robert D. Washburn; Carlos H. Gonzalez; Jerry C. Sze and David M. Lusher

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Complete Specification for the invention entitled:

CAPACITIVE COUPLED POWER SUPPLIES

The following statement is a full description of this invention, including the best method of performing it known to me/us:-

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CAPACITIVE COUPLED POWER SUPPLIES

BACKGROUND OF THE INVENTION

The disclosed invention is generally directed to rectifying power supplies, and is more particularly directed to a high frequency rectifying power supply which does not utilize a complex transformer.

Rectifying power supplies are utilized in certain applications where the required supply voltage is DC. The originating power source may provide an AC voltage or a DC voltage. With a DC voltage supply, stepping the voltage up or down requires conversion of the DC power to AC power which may be accomplished, for example, with a square wave converter or a sinewave converter. Typically, the AC voltage is generally stepped up or stepped down as required by a transformer, and then rectified.

Significant improvements in the size and weight of rectifying power supplies have been made by increasing the operating frequency of the AC power. Particularly, higher operating frequencies allow for significantly smaller capacitive elements. However, operating frequencies have been limited by certain considerations including the increase of transformer size with frequency, and the inability of known transformer designs to operate at frequencies greater than one MHz. Particularly, with increased AC operating frequencies, transformer isolation is reduced, reflections increase, and core losses increase. As a result of problems encountered with increased frequencies, different transformer designs have been made in attempts to allow for higher AC operating frequency

operation. Such designs, however, are complex and generally require time-consuming and costly development for particular applications. Moreover, such transformer designs do not provide significant increases in AC operating frequencies, and moreover are bulky.

A further consideration in the implementation of high frequency power supplies is the power handling limits of available diodes. If the number of secondary windings is reduced in attempting to make transformers smaller and less complex, then the the power limits of available diodes may be exceeded. If more secondary windings are used to accommodate the power limits of available diodes, then transformer complexity and size increase.

SUMMARY OF THE INVENTION

It would therefore be an advantage to provide a high frequency rectifying power supply which does not utilize a complex and bulky transformer.

It would also be an advantage to provide a high frequency rectifying power supply which has an AC operating frequency of greater than 1 MHz.

Another advantage would be to provide a rectifying power supply having an AC operating frequency of greater than 1 MHz which does not utilize a complex and bulky transformer.

According to the present invention there is provided a power supply comprising:

means for providing AC power at a frequency greater than one megahertz;

non resonant means responsive to said AC power for providing DC isolation and for providing capacitively coupled AC Power without inductors or resistors; and

a plurality of rectifying means responsive to said capacitively coupled AC power for providing respective DC outputs.

BRIEF DESCRIPTION OF DRAWING

The advantages and features of the disclosed invention will readily be appreciated by persons skilled in the

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art from the following detailed description when read in conjunction with the drawing wherein:

FIG. 1 is a block diagram of a rectifying power supply in accordance with the invention wherein the outputs of the power supply rectifier/filter modules are serially coupled.

FIG. 2 is a schematic diagram of a rectifier/filter module which may be used in the power supply of FIG. 1.

FIC. 3 is a block diagram of further rectifying power supply in accordance with the invention.

FIG. 4 is a block diagram of another rectifying power supply in accordance with the invention.

DETAILED DESCRIPTION

In the following detailed description and in the several figures of the drawing, like elements are identified with like reference numerals.

Referring now to FIG. 1, illustrated therein is a high frequency rectifying power supply 10 which includes a sinewave source 11 that is responsive to a DC supply voltage V_{in}. By way of example, V_{in} may be 200 volts. The sinewave source 11 can comprise known circuitry for converting a DC voltage to an AC voltage that varies sinusoidally. Alternatively, a square wave source may also be utilized. By way of more specific example, the sinewave source 11 may also include a low ratio transformer for providing transformer isolation and, if appropriate, a relatively small step-up or step-down in voltage. The ratio of such isolation transformers can range from (5:1) to (1:5).

The output of the sinewave source 11 has a peak voltage denoted V_p and is coupled via output lines 13, 15 to a rectifier/filter module 20. The rectifier/filter module 20 may be of conventional design for providing full wave rectification and filtering to provide a DC voltage output. A conventional example of circuitry for the

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rectifier/filter module 20 is discussed further herein in conjunction with FIG. 2.

Coupling capacitors 19, 21 have first terminals respectively coupled to the output lines 13, 15. The second terminals of the coupling capacitors 19, 21 are coupled to the input of a rectifier/filter module 23, which may be of the same circuit structure as the rectifier/filter module 17.

The second terminals of the coupling capacitors 19, 21 are further coupled to the first terminals of coupling capacitors 25, 27. The second terminals of the coupling capacitors 25, 27 are coupled to the input of a rectifier/filter module 29, which may be of the same circuit structure as the rectifier/filter modules 17, 23 discussed above.

The second terminals of the coupling capacitors 25, 27 are further coupled to the further coupling capacitors 31, 33. The second terminals of the coupling capacitors 31, 33 are coupled to an associated rectifier/filter module (not shown).

As shown in FIG. 1, N rectifier/filter modules may be utilized, the rectifier/filter module 35 being the N^{th} module, with all of the rectifier/filter modules having associated coupling capacitors, except for the first one, which in this case is identified with the reference numeral 17. In essence, a pair of coupling capacitors is associated with each of the rectifier/filter modules that are in addition to the first rectifier/filter module 17. Such coupling capacitors are interposed between the inputs to the different rectifier/filter modules and are serially coupled.

As also shown in FIG. 1, the outputs of the rectifier/filter modules are connected serially to provide a maximum output voltage that is the sum of the respective output voltages. As discussed further below with respect

to FIG. 2, the outputs of the rectifier/filter modules can be across respective output capacitors, and with such structure, the output capacitors of the rectifier/filter modules would be coupled serially. As indicated in FIG. 1, the first terminal of the output capacitor of the rectifier/filter module 17 is coupled to a common reference potential, which may be considered ground. All output voltages are with respect to such common reference potential. The second terminal of the output capacitor of the rectifier/filter module 17 is connected to the first terminal of the output capacitor of the rectifier/filter module 23, and so forth. The second terminal of the N^{th} rectifier/filter module 35 provides a high voltage output which is the sum of the outputs of all of the rectifier/filter modules. The third rectifier/filter module 29 provides an output voltage which is the sum of the outputs provided by it and the preceding rectifier/filter modules. The outputs respectively provided by the second and first rectifier/filter modules should be readily evident.

Assuming small losses in the coupling capacitors, the output voltage V_{out} provided at the N^{th} rectifier/-filter module 35 is approximately two-thirds of N times the peak voltage V_p provided by the sinewave source 11.

It should be noted that the increase in the equivalent series resistance of the coupling capacitors provides a limit on the number of rectifier/filter modules that can be utilized in the power supply 10. For example, for an AC operating frequency greater than 1 MHz and an input voltage of 200 volts, it has been determined that 20-30 rectifier/filter modules appears to be a reasonable upper limit with the circuit structure of the FIG. 1. A greater number may result in unacceptable open loop regulation, while in a closed loop system the variation would have to be absorbed in the dynamic range of the power supply 10. Further, high equivalent series resistance results in high

power dissipation, which results in shorter component lifetimes. An alternate configuration that addresses these considerations is discussed further herein relative to FIG. 3.

Referring now to FIG. 2, illustrated therein is a schematic of a rectifier/filter module 20 which may be utilized in the power supply 10 of FIG. 1. Specifically, the rectifier/filter module 20 includes a first pair of serially connected diodes 111, 113 in parallel with a second pair of serially connected diodes 115, 117. A pair of balanced inductors 121, 123 are connected in series with the diode pairs, and function to ensure continuous operation of the diodes 111, 113, 115, 117. A smoothing capacitor 119 is connected in series with the balanced inductors 121, 123. The output of the rectifier/filter module 20 is across the smoothing capacitor 119.

Referring now to FIG. 3, a high voltage rectifying power supply 30 includes a sinewave source 211 which is responsive to a DC input voltage V_{in}, which by way of example may be 200 volts. The output of the sinewave source 211 has a peak voltage denoted V_p and is on output lines 213, 215. The first terminals of coupling capacitors 217, 219 are coupled to the sinewave source output lines 213, 215. The second terminals of the capacitors 217, 219 are connected to the input of a rectifier/filter module 211, which may be of conventional design such as the rectifier/filter module 20 of FIG. 2.

The first terminals of coupling capacitors 223, 225 are respectively coupled to the output lines 213, 215 of the sinewave source 211. The second terminals of the coupling capacitors 223, 225 are coupled to the input of a rectifier/filter module 227 which also may be of conventional design such as the rectifier/filter module 20 of FIG. 2.

Further rectifier/filter modules and associated coupling capacitors can be coupled to the output lines 213, 215, as illustrated by the N^{th} pair of coupling capacitors 229, 231 and the associated N^{th} rectifier/-filter module 233.

In the high voltage rectifying power supply 30 of FIG. 3, each of the rectifier/filter modules is coupled to the output of the sinewave source 211 via respective coupling capacitors.

The outputs of the rectifier/filter modules 221, 227, 233 are coupled in series to provide a high voltage output V_{out}. Again assuming small losses in the coupling capacitors, the output voltage provided by the serially coupled rectifier/filter outputs is approximately two-thirds of N times the peak output voltage V_p of the sinewave source 211.

Since the coupling capacitors in the power supply 30 are not serially coupled as to each other, more rectifier/filter modules can be utilized with the power supply 30 of FIG. 3 than with the power supply 10 of FIG. 1. Thus, the power supply 30 can provide for a greater step-up in voltage.

Referring now to FIG. 4, shown therein is a rectifying power supply 40 which may be utilized to provide lower voltages with high current. Specifically, power supply 40 is similar to the power supply 30 of FIG. 3, except that the outputs of the rectifier/filter modules of the power supply 40 are coupled in parallel. The output voltage provided by the power supply 40 is approximately two-thirds the peak output voltage V_p provided by the sinewave source 311. The available current will be high as a result of the parallel configuration of the outputs of the rectifier/filter modules.

The following are examples of operating parameters and component values for the power supply 10 of FIG. 1, where the F_s is the frequency of the output of the sine-wave source 11 which has a peak voltage V_p:

V_{in}: 200 volts
V_p: 1200 volts
F_s: 2 MHz
V_{out}: 10.4 kilovolts
Total Power: 1 kilowatt
Capacitors 19, 21, 25, 27, 31, 33: 50,000 picofarads
Inductors 121, 123: 120 microhenrys
Diodes 111, 113, 115, 117: Type SPD524, Solid State Devices, La Mirada, California
Filter Capacitor 119: 2,000 picofarads
Number of rectifier/filter modules: 13

The following are examples of operating parameters and component values for the power supply 30 of FIG. 3, where the F_s is the frequency of the output of the sine-wave source 211 which has a peak voltage V_p:

V_{in}: 200 volts
V_p: 1200 volts
F_s: 2 MHz
V_{out}: 8.0 kilovolts
Total Power: 4 kilowatts
Capacitors 217, 219, 223, 225, 229, 231: 50,000 picofarads
Inductors 121, 123: 24 microhenrys
Diodes 111, 113, 115, 117: Type SPD524, Solid State Devices, La Mirada, California
Filter Capacitor 119: 13,000 picofarads
Number of rectifier/filter modules: 10

The following are examples of operating parameters and component values for the power supply 40 of FIG. 4, where the F_s is the frequency of the output of the sine-wave source 311 which has a peak voltage V_p:

V_{in}: 30 volts
V_p: 7.5 volts
F_s: 10 MHz
V_{out}: 5 volts
Total Power: 7.5 watts
Capacitors 317, 319, 323, 325, 329, 331: 50,000 picofarads
Inductors 121, 123: 24 microhenrys
Diodes 111, 113, 115, 117: Type 31DQ03, International Rectifier, El Segundo, California
Filter Capacitor 119: .025 microfarads
Number of rectifier/filter modules: 5

While the foregoing power supply structures have been discussed as stand-alone circuits, it should be readily appreciated that they can comprise modular building blocks which can be connected in series or parallel to achieve the desired voltage and/or current outputs.

The foregoing has been a disclosure of a rectifying power supply structure which eliminates the need for an expensive and complex transformer, operates at frequencies greater than 1 MHz, and provides other distinct advantages. Such other advantages include uncomplicated design with predictable response, adaptability for a modular structure, adaptability for use as compact, inexpensive building blocks, which reduces cost in both development and manufacturing. Other advantages include low stored energy in the power supply, and faster open loop response for regulated power supply applications. Still further advantages include reduced size and weight, and increased efficiency and reliability. Finally, since the limitations of high voltage transformers do not come into play,

the disclosed invention allows for AC operating frequencies substantially higher than what is presently practical.

Although the foregoing has been a description and illustration of specific embodiments of the invention, various modifications and changes thereto can be made by persons skilled in the art without departing from the scope and spirit of the invention as defined by the following claims.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A power supply comprising:

means for providing AC power at a frequency greater than one megahertz;

non resonant means responsive to said AC power for providing DC isolation and for providing capacitively coupled AC Power without inductors or resistors; and

a plurality of rectifying means responsive to said capacitively coupled AC power for providing respective DC outputs.

2. The power supply of Claim 1 wherein the non resonant means comprises a plurality of capacitors which are serially connected, and wherein said plurality of rectifying means are connected to respectively associated ones of said capacitors.

3. The power supply of Claim 2 further including other rectifying means directly connected to said AC power providing means for providing a DC output.

4. The power supply of Claim 3 wherein said DC outputs of said plurality of rectifying means and said other rectifying means are serially connected.

5. The power supply of Claim 1 wherein the non resonant means comprises a plurality of capacitors each of which is directly connected to said AC power providing means and wherein each of said rectifying means is respectively associated with certain ones of said plurality of capacitors.

6. The power supply of Claim 5 wherein said DC outputs of said plurality of rectifying means are serially connected.

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7. The power supply of Claim 5 wherein said DC outputs of said plurality of rectifying means are connected in parallel.

Dated this 9th day of March 1989

HUGHES AIRCRAFT COMPANY
By their Patent Attorney
GRIFFITH HACK & CO.

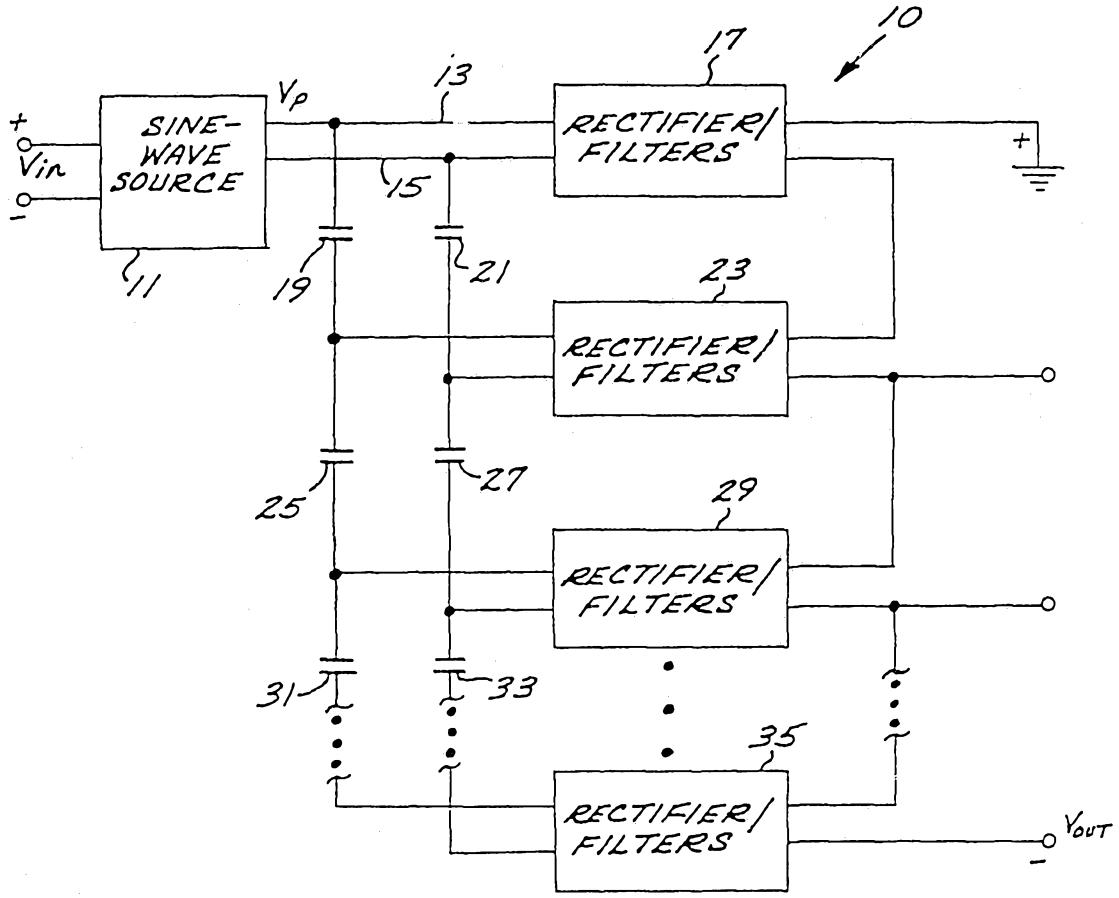

10
17
13
Vp
SINE-WAVE SOURCE
+
Vin
−
11
15
19
21
23
RECTIFIER/FILTERS
25
27
29
31
33
35
+
VOUT
−

FIG. 1

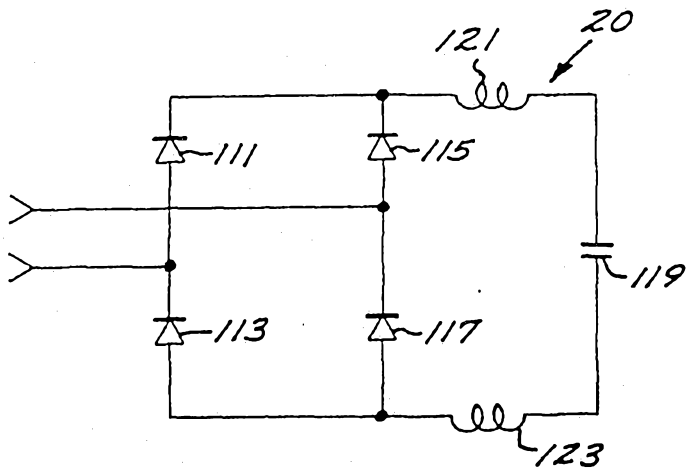

121
20
111
115
119
113
117
123

FIG. 2

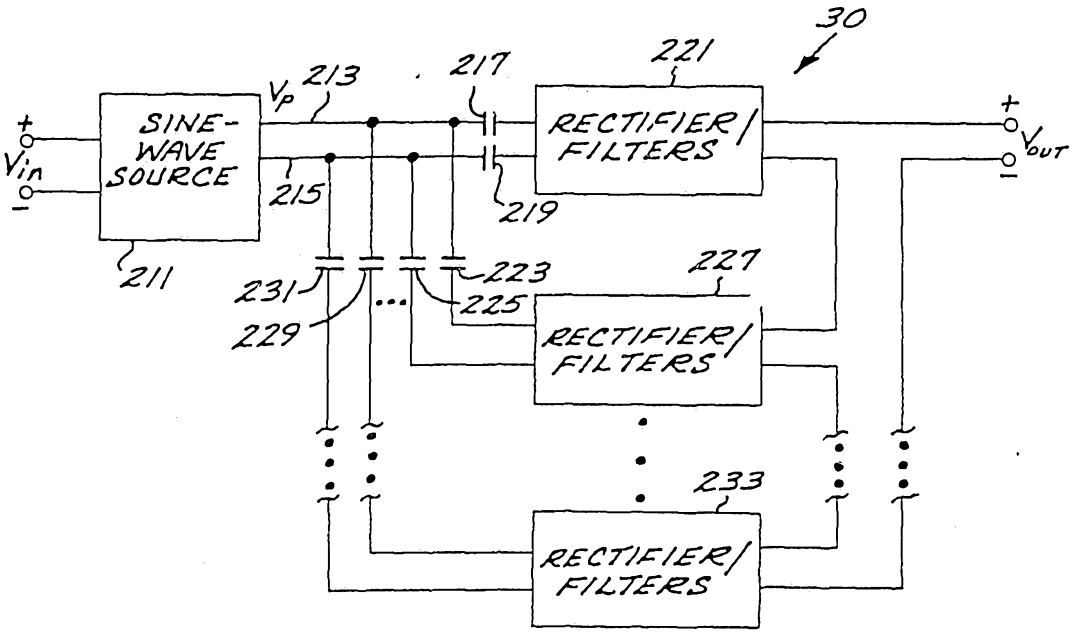

30
221
217
213
V_p
SINE-WAVE SOURCE
V_{in}
+
−
215
219
211
231
229
223
225
227
RECTIFIER/FILTERS
233
RECTIFIER/FILTERS
RECTIFIER/FILTERS
+
V_{out}
−

FIG. 3

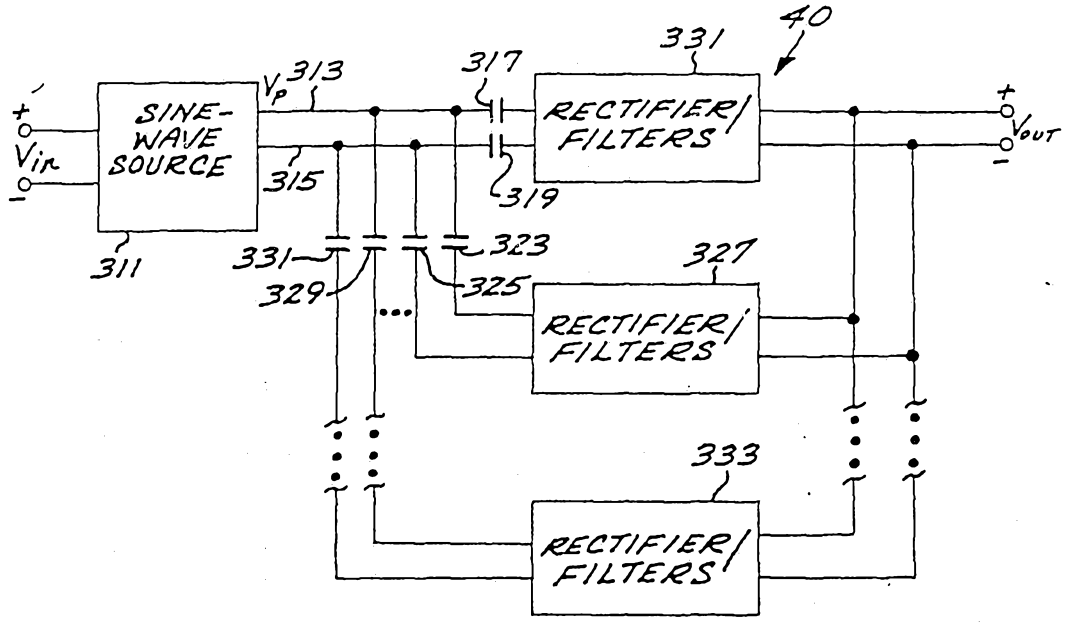

40
331
317
313
V_p
SINE-WAVE SOURCE
V_{in}
+
−
315
319
311
331
329
323
325
327
RECTIFIER/FILTERS
333
RECTIFIER/FILTERS
RECTIFIER/FILTERS
+
V_{out}
−

FIG. 4