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— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

[Continued on next page]

(54) Title: SWITCHER NOISE REDUCTION

(57) Abstract: There is provided a power supply including a switching stage and a shunt network, the shunt network being connected to the output of the switching stage and configured to reduce the noise signal associated with the switching stage.

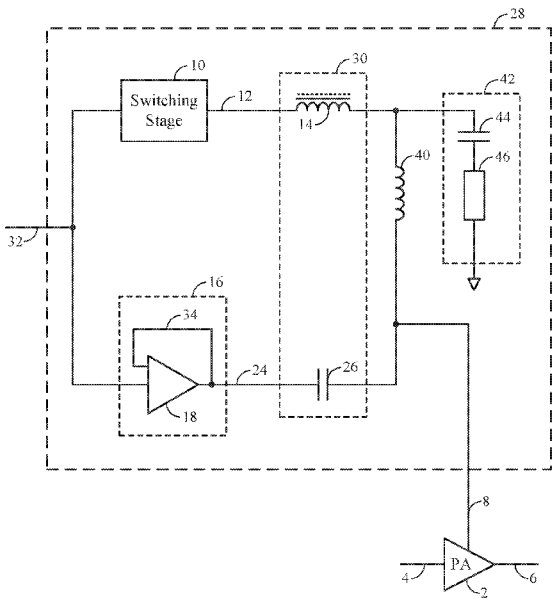

FIG. 5

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— *with international search report (Art. 21(3))*

SWITCHER NOISE REDUCTION

CROSS-REFERENCE TO RELATED APPLICATIONS:

This application claims priority to GB Application No. 1502246.0, filed February 11, 2015.

BACKGROUND TO THE INVENTION:

Field of the Invention:

The present invention relates to power supplies incorporating switching stages, and particularly but not exclusively to envelope tracking power supplies for radio frequency power amplifiers.

Description of Related Art:

An envelope tracking power supply for a radio frequency power amplifier is an example of a power supply incorporating switches. The switches in a switching stage of such a power supply switch between different supply levels in order to generate an output power supply.

For efficient power supplies it is advantageous in at least some scenarios to minimise any noise associated with such switching, in order to avoid such noise being present on the power supply itself.

It is an aim of the present invention to reduce the switching noise caused by switching in a switched power supply.

SUMMARY OF THE INVENTION:

There is provided a power supply including a switching stage and a shunt network, the shunt network being connected to the output of the switching stage and configured to reduce the noise signal associated with the switching stage.

The shunt network may be configured to reject high frequency signals in the output signal of the switching stage.

The shunt network may be a shunt impedance.

The power supply may further comprise a switch for connecting the shunt network to electrical ground. The switch may be controlled to be closed when noise reduction is required, and open when noise reduction is not required.

The power supply may further include a correction stage and a combiner, the combiner for combining the outputs of the switching stage and the correction stage to generate a supply voltage, the combiner comprising a combining inductor having a first terminal for receiving the output of the switching stage and a second terminal for providing the power supply output, the shunt network being connected to either the first or the second terminal of the combining inductor.

The power supply may further comprise an isolating inductor, the first terminal of the combining inductor being connected to the output of the switching stage, and the second terminal of the combining inductor being connected to the power supply output via the isolating inductor.

The power supply may further comprise an isolating inductor, the second terminal of the combining inductor providing the combiner output, and the isolating inductor being connected between the first terminal of the combining inductor and the switching stage output.

The shunt network may comprise a series connected capacitor and resistor arrangement, the arrangement having a first terminal connected to the second terminal of the combining inductor and a second terminal connected to electrical ground.

The combiner may further comprise a capacitor connected between an output of the correction stage and the output of the power supply.

BRIEF DESCRIPTION OF THE FIGURES:

The invention is described by way of reference to the accompanying figures, in which:

FIG. 1 illustrates an exemplary envelope tracking power supply for an RF PA;

FIG. 2 illustrates the ripple current due to switching noise in the exemplary envelope tracking modulator of FIG. 1;

FIG. 3 illustrates an improvement to the exemplary envelope tracking modulator power supply of FIG. 1;

FIG. 4 illustrates the ripple current due to switching noise in the improved envelope tracking modulator of FIG. 3;

FIG. 5 illustrates a modification to the improved exemplary envelope tracking modulator power supply of FIG 3; and

FIG. 6 illustrates an alternative improvement to the exemplary tracking modulator of FIG. 1.

DESCRIPTION OF PREFERRED EMBODIMENTS:

The invention is now described with reference to particular examples and with reference in particular to an example of a switched power supply stage of an envelope tracking modulated power supply for a radio frequency amplifier. The invention is not limited to such an example implementation.

With reference to **FIG. 1** a power supply stage 28 provides a modulated supply voltage on line 8 to a power amplifier (PA) 2. The PA 2 receives a radio frequency (RF) input signal on line 4 and generates an RF output signal on line 6. The power supply stage 28 tracks the envelope of an RF input signal on line 4 to be amplified in order to provide an efficient modulated power supply on line 8 to the PA 2.

The power supply stage 28 includes a switching stage 10, a correction stage 16, and a combiner 30 including an inductor 14 and a capacitor 26. The switching stage 10 generates a switched voltage output signal on line 12. Line 12 is connected to a first terminal of the inductor 14. The second terminal of the inductor 14 is connected to the output line 8. The correction stage 16, which includes a correction amplifier 18, generates a correction voltage on line 24. Line 24 is connected to a first terminal of the capacitor 26. The second terminal of the capacitor 26 is connected to the output line 8. The inductor 14 and capacitor 26 together form the combiner 30 which combines the output voltages from the switching stage and the correction stage to produce the modulated supply voltage on line 8. The correction amplifier 18 has a feedback connection line 34 connecting its output to a first input. The correction stage has a second input connected to receive a reference signal on line 32. The correction amplifier compares the feedback signal on line 34 to the reference signal in order to

generate the correction signal. The reference signal on line 32 represents a desired output signal. The reference signal is additionally provided to the switching stage 10.

The switching stage 10 produces an output switching current, or ripple current, at the switching frequencies of the switches in the switching stage 10. This current is converted to switching voltage noise by the combiner 30 when driving a resistive load such as a PA 2. This noise is undesirable, particularly in the amplification of low level signals.

FIG. 2 illustrates a plot of the switching noise signal, being a plot of the ripple current against time. The plot 3 is a plot of ripple current versus time, the ripple current being the current due to switching which flows in the inductor 14. The ripple current is undesirable. The ripple current has distortions at each maxima and minima, as illustrated by reference numeral 5. **FIG. 2** illustrates a plot of only the unwanted noise signal: in addition there is a wanted signal.

FIG. 3 illustrates a modified modulated power supply stage 40. Where elements shown correspond to elements shown in the previous figure like reference numerals are used.

A circuit 42 is connected at the second terminal of the inductor 14. The circuit 42 includes a capacitor 44 having a first terminal connected to the second terminal of the inductor 14. A resistor 46 has a first terminal connected to the second terminal of the capacitor 44. A switch 48 is connected between the second terminal of the resistor 46 and electrical ground.

The circuit 42 is an anti-ripple circuit which acts to reduce the ripple current in the current flowing through the inductor 14.

An inductor 40 is connected between the second terminal of the inductor 14 and the output on line 28, having a first terminal connected to the second terminal of the inductor 14 and a second terminal connected to the output on line 8. The second terminal of the inductor 40 is connected to the second terminal of the capacitor 26.

The inductor 40 isolates the output of the power supply on line 8 from the shunt impedance provided by the circuit 42.

The provision of the anti-ripple circuit 42 allows the ripple current to be reduced before it gets to the output on line 8.

The anti-ripple circuit preferably reduces the undesirable ripple current due to switching by significantly reducing, preferably by substantially eliminating, the high frequency portions of the ripple current.

FIG. 4 illustrates a plot of the switching noise signal for the circuit of **FIG. 3**. The plot 7 is a plot of ripple current versus time, the ripple current being the current due to switching flowing in the inductor 40. The ripple current does not have distortions at each maxima and minima, as illustrated by reference numeral 7, due to the high frequency portions of the switching noise signal being substantially eliminated. Thus the maxima and minima distortions illustrated in **FIG. 2** have been substantially eliminated.

The anti-ripple circuit is connected to electrical ground by the switch 48 such that the anti-ripple circuit can be disconnected when low noise is not required or noise associated with switching is not an issue. A control signal is provided to control the switch.

In an alternative the switch 48 may not be required, with the second terminal of the resistor being connected permanently to electrical ground. **FIG. 5** illustrates an alternative implementation to **FIG. 3** in which the switch is not provided, the second terminal of the resistor 46 being connected to electrical ground.

The inductor 14 is the combining inductor, and the inductor 40 is an isolation or isolating inductor, to isolate the anti-ripple circuit from the power supply output so that the short circuit effect of the anti-ripple circuit 42 is isolated from the power supply output. The inductor 40 is much smaller than the inductor 14. Typically the size ratio of the inductor 14 to the inductor 40 is 10:1.

In an alternative, the positions of the isolating inductor 40 and the combining inductor 14 may be switched. Suh an arrangement is shown in **FIG. 6**. **FIG. 6** corresponds to the arrangement of **FIG. 3**, but the isolating inductor is connected to the output of the switching stage 30, and the combining inductor 14 (of the combiner 30) is connected between the isolating inductor and the combiner output. The anti-ripple circuit is connected at the connection between the combing circuit and the isolating inductor.

In the arrangement of **FIG. 6**, the isolating inductor isolates the switching stage from the anti-ripple circuit 42.

In general, therefore, it may be considered that the anti-ripple circuit can be connected to either terminal of the combining inductor of the combiner, and then the isolating inductor is connected between to isolate either the combiner from the anti-ripple circuit or to isolate the switching stage from the ripple circuit, depending on where the anti-ripple circuit is connected.

Although the arrangement of **FIG. 6** is shown as a modification to the arrangement of **FIG. 3**, the modification of **FIG. 5** may also be applied in **FIG. 6**.

The anti-ripple circuit 42 can be any shunt network that provides rejection at high frequency. The anti-ripple circuit 42 may contain elements other than the resistor 46 and capacitor 44. In general the anti-ripple circuit is a shunt network or shunt impedance to shunt only high frequency components, and not low frequency ripple noise or the actual signal.

In embodiments the combiner 30 may comprise only the inductor 14.

The invention has been described by way of reference to examples. The invention is not limited to the detail of any example and any aspect described may be implemented alone or in combination. The scope of the invention is defined by the appended claims.

CLAIMS:

1. A power supply comprising:

a switching stage;

a correction stage;

a combiner connected with an output of the switching stage and an output of the correction stage and configured to combine output signals of the switching stage and the correction stage to generate a power supply signal; and

a shunt network connected with the combiner and configured to reduce noise in the output signal of the switching stage.

2. The power supply of claim 1, wherein the shunt network is configured to reject high frequency signals in the output signal of the switching stage.

3. The power supply of claim 1, wherein the shunt network comprises a shunt impedance.

4. The power supply of claim 1, further comprising a switch connected with the shunt network and configured to selectively connect the shunt network to electrical ground.

5. The power supply of claim 4, wherein the switch is controlled to be closed when noise reduction is selected and to be open when noise reduction is not selected.

6. The power supply of any preceding claim, wherein the combiner comprises a first inductor having a first terminal connected with the output of the switching stage and a second terminal connected with an output of the power supply having the power supply signal, the shunt network being connected with either the first or the second terminal of the first inductor.

7. The power supply of claim 6, further comprising a second inductor having a first terminal connected with the second terminal of the first inductor, a second terminal of the second inductor connected with the output of the power supply.

8. The power supply of claim 6, further comprising a second inductor, the second terminal of the first inductor connected with the output of the power supply and providing the power supply signal, wherein the second inductor is connected between the first terminal of the first inductor and the output of the switching stage.

9. The power supply of claim 7 or claim 8, wherein the shunt network comprises a series-connected capacitor and resistor arrangement, the arrangement having a first terminal connected between at a junction between the first inductor and the second inductor and a second terminal connected with electrical ground.

10. The power supply of any one of claims 6 to 9, wherein the combiner further comprises a capacitor connected between the output of the correction stage and the output of the power supply.

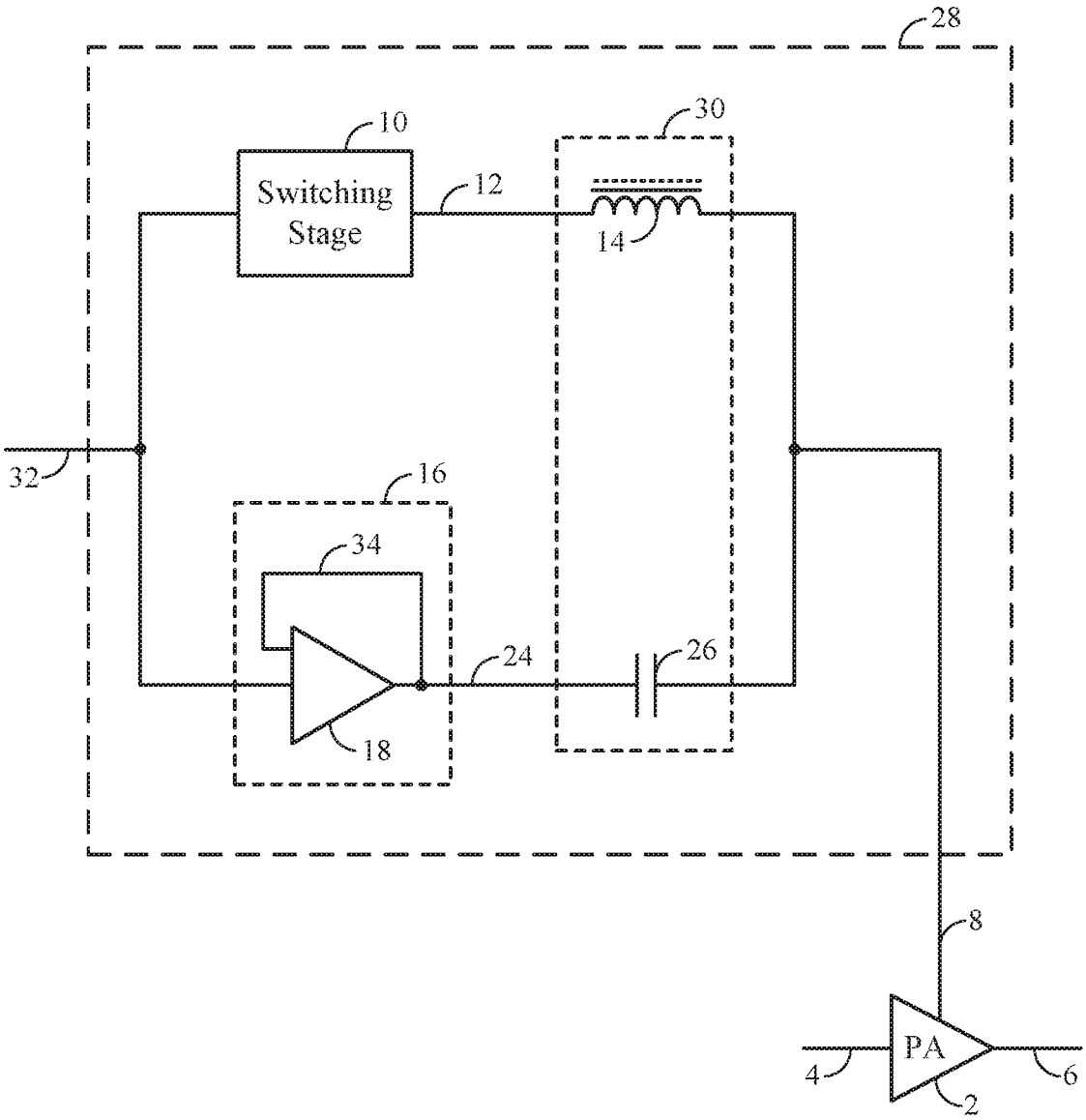


FIG. 1

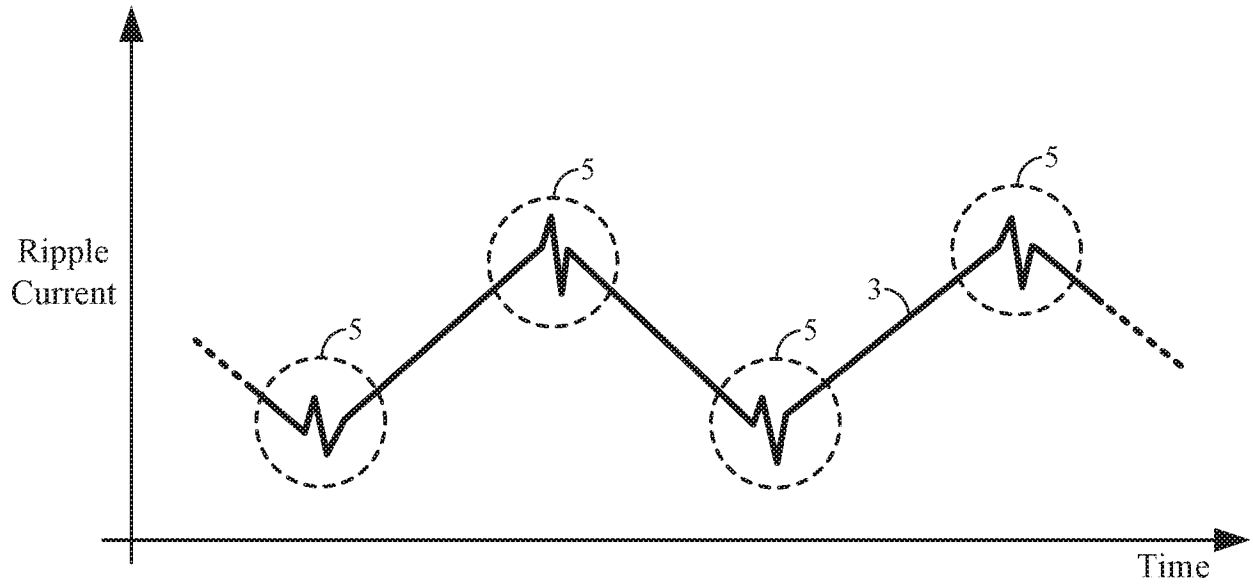
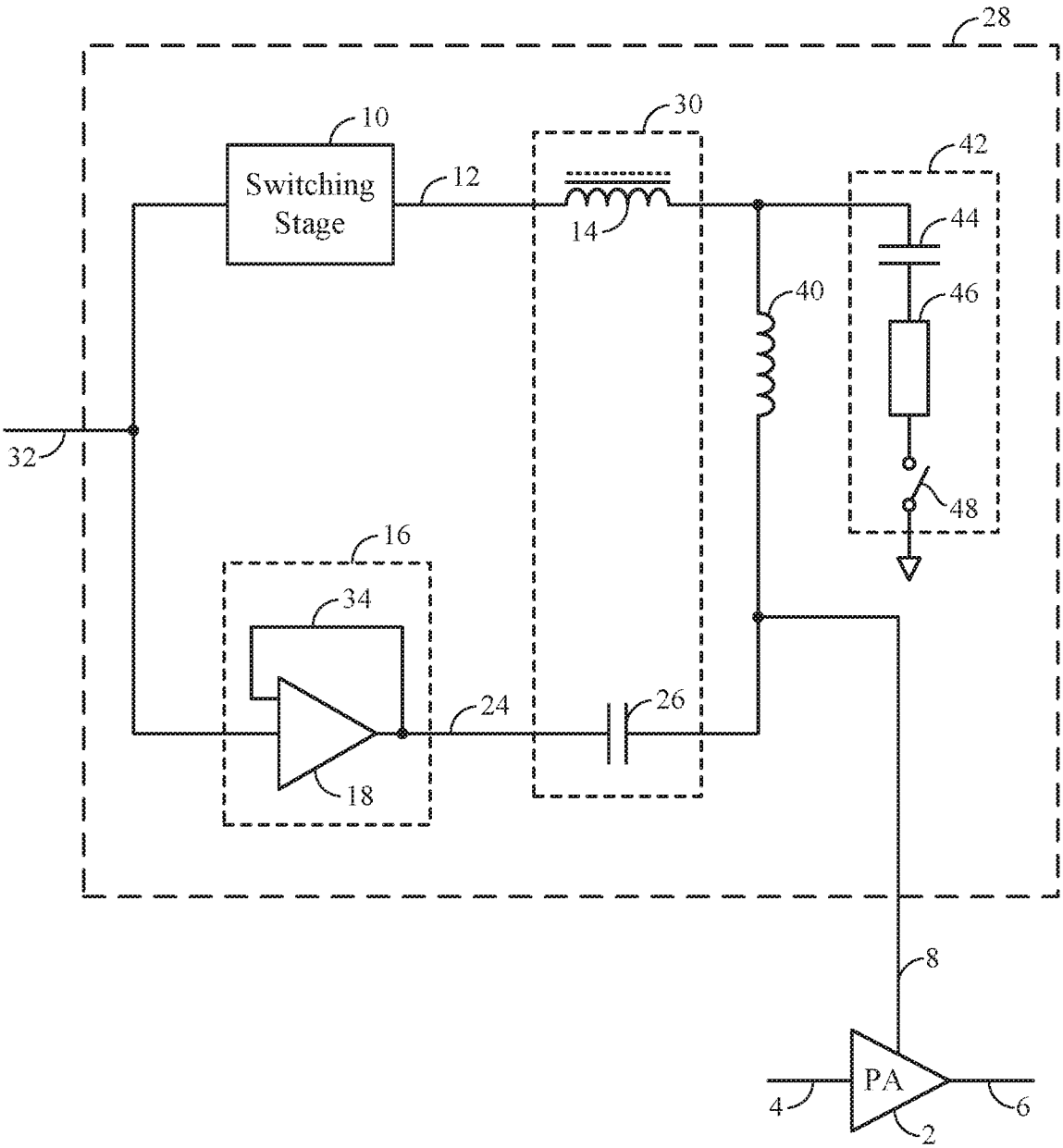


FIG. 2


28
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Switching Stage
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PA
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FIG. 3

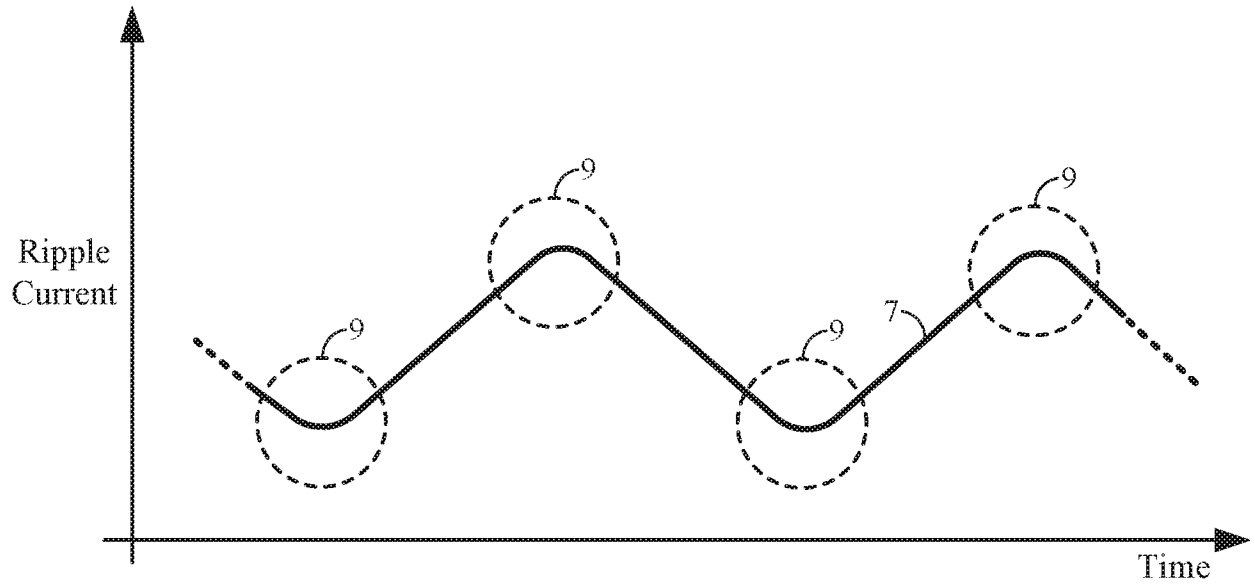

FIG. 4

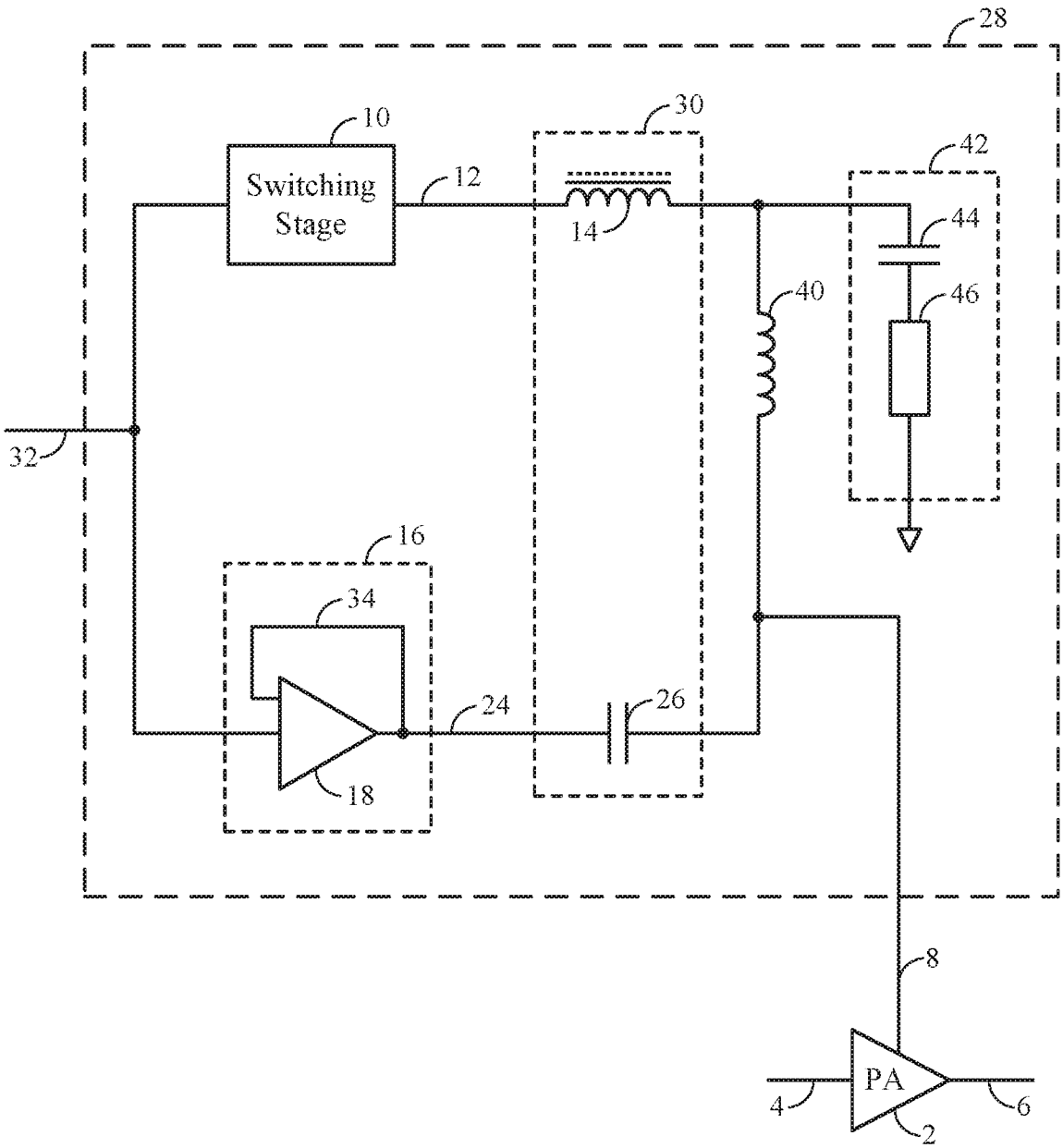
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FIG. 5

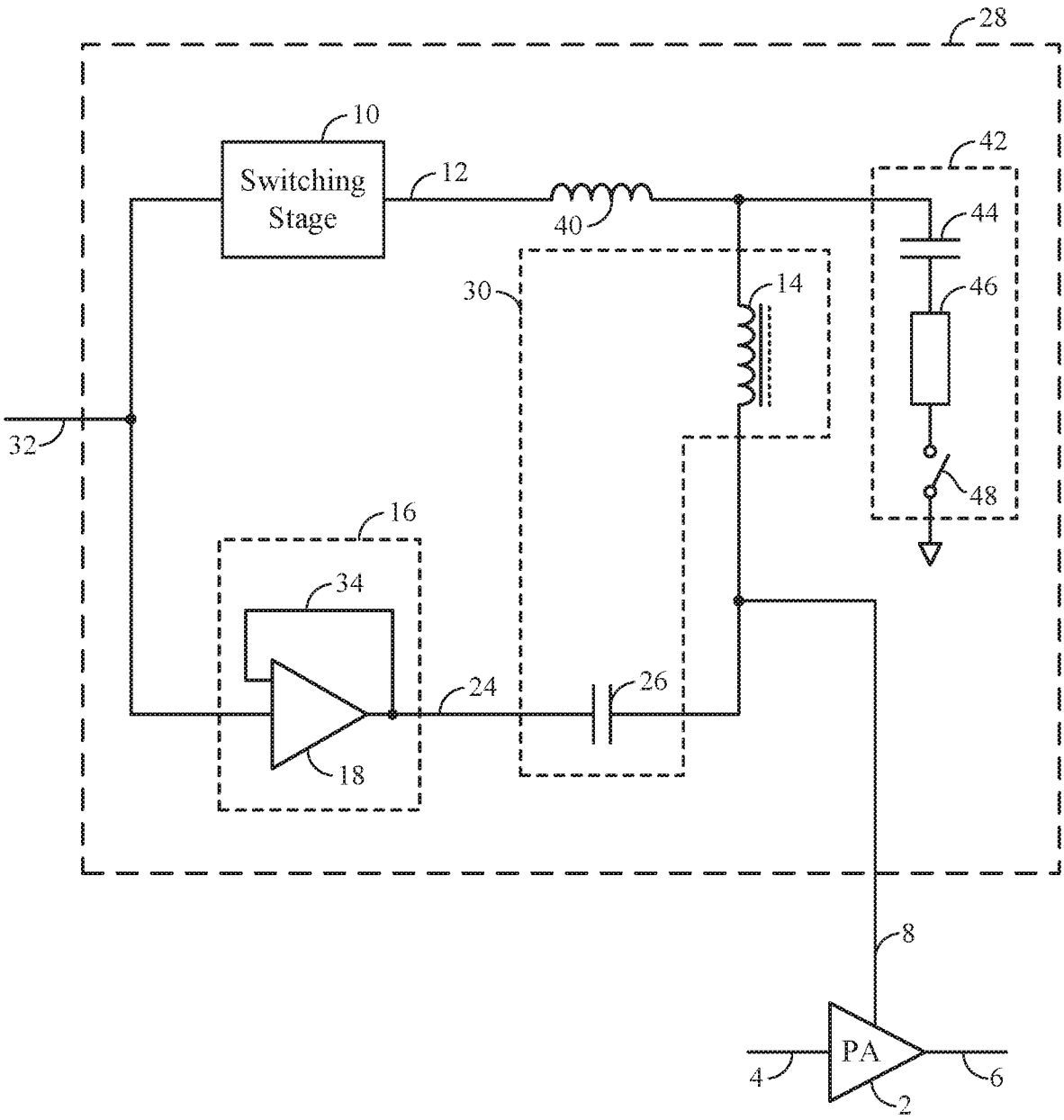
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FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/017520

A. CLASSIFICATION OF SUBJECT MATTER
INV. H03F1/02
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H03F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014/285164 A1 (OISHI KAZUAKI [JP] ET AL) 25 September 2014 (2014-09-25) paragraph [0144] - paragraph [0161]; figure 18	1-6
X	US 2013/207731 A1 (BALTEANU FLORINEL G [CA]) 15 August 2013 (2013-08-15) paragraph [0180] - paragraph [0188]; figure 16A	1-3,6-10
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
26 May 2016	02/06/2016

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/017520

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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