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(71) Applicant (for all designated States except US): **BERNAFON AG** [CH/CH]; Morgenstrasse 131, CH-3018 Bern (CH).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **KURATLI, Christoph** [CH/CH]; Bernafon AG, Morgenstrasse 131, CH-3018 Bern (CH).

(74) Agent: **CHRISTENSEN, Mikael, T.**; Oticon A/S, Strandvejen 58, DK-2900 Hellerup (DK).

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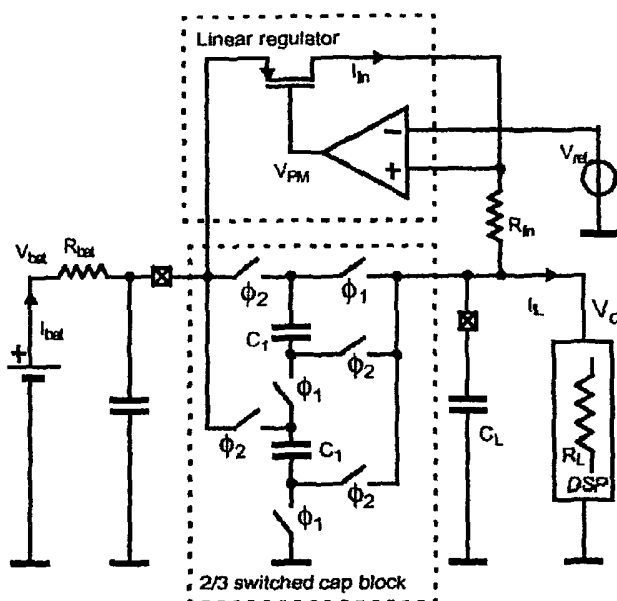
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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: POWER SUPPLY ARRANGEMENT FOR BATTERY POWERED DEVICE



(57) Abstract: The invention relates to a method for conversion of a battery voltage in a battery powered headworn communication device, the method comprising providing a voltage reduction to a fixed part of the input voltage and providing a variable reduction that ensures that a minimum voltage is maintained. Preferably the fixed part reduction and the variable reduction are performed in parallel and the fixed voltage conversion is a 2/3 conversion of the input voltage. Also advantageous is it when a fixed voltage conversion and the variable voltage conversion are balanced according to the actual battery voltage. The invention further relates to a battery powered headworn communication device.

POWER SUPPLY ARRANGEMENT FOR BATTERY POWERED DEVICE

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The invention relates to the area of power supply systems for use in connection with battery powered headworn communication devices. More specifically the invention relates to power supply systems where the battery voltage is higher than desired and
10 therefore need to be reduced. Such battery-powered devices may be hearing aids, telephone headsets and other mobile devices.

BACKGROUND OF THE INVENTION

15 In connection with battery powered headworn communication devices it is previously known to use a switched mode power supply based on a class-D driver and an external LC-lowpass filter. This solution has a good efficiency but suffers from a variety of problems due to the presence of an inductor, which gives rise to magnetic interference, stability problems and in some cases size problems. Another idea is to use a switched
20 capacitor step down converter, which in no-load condition would linearly transform the battery voltage to a fraction of it. In principle, this would have a satisfactory function, however, for battery voltages below a certain voltage the output supply can no longer be guaranteed to be the desired. Low battery voltage may occur gradually or instantaneously (sudden load changes) during lifetime of the battery. A third possibility is to use linear
25 regulators to provide a lower voltage than the battery voltage, however a drawback for such conversion is that the energy efficiency is poor. High efficiency is however a very important aspect for battery operated applications where lifetime of the battery may be crucial for the individual in need of such battery-operated device.

30 The objective of the invention is therefore to provide a power conversion method and system for battery operated applications, where the energy efficiency is improved compared to previously known linear regulator systems, which does provide a stable

power supply and which still is capable of maintaining a sufficient voltage for the battery operated application.

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SUMMARY OF THE INVENTION

According to the invention this objective is achieved by means of the method as defined in claim 1.

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By performing the conversion in this manner there has been provided an opportunity for a more energy efficient conversion than hitherto known in connection with battery powered headworn communication devices. The conversion may be performed in a stable manner and a sufficient voltage can be maintained during the lifetime of the battery.

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Advantageous embodiments are defined in the dependent claims 2-5.

By the embodiment set forth in claim 2 the two systems are operated in parallel hereby enabling a simple implementation.

20

The reduction fraction is preferably $2/3$, but in principle any fraction may be achieved.

25

By balancing the fixed part voltage conversion and the variable part conversion, a possibility of optimising the efficiency of the system may be achieved. In a system comprising a switched capacitor part this is preferably done by setting the clock frequency of the switched capacitor part.

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Further according to the invention the objective is achieved by means of the system as defined in claim 6.

By means of the system defined in claim 6 the same advantages as mentioned in connection with the method may be achieved.

Advantageous embodiments are defined in the dependent claims 7 to 11 hereby achieving the same advantages as defined above in connection with the method according to the invention.

- 5 The invention will be described more detailed in connection with the following description of a preferred embodiment with reference to the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

- 10 FIG. 1A and FIG. 1B are block diagrams showing a combined switched capacitor/linear DC/DC power supply;
FIG. 2 shows typical DC transfer characteristics for the system according to the invention;
FIG. 3 shows output current and voltage in the linear regulator as part of the overall
15 supply system;
FIG. 4 is a block diagram showing an automatic adapting system;
FIG. 5 shows behaviour of voltages and currents in an automatically adapting system;
FIG. 6 shows behaviour of an automatically adapting system using transistor level schematics;
20 FIG. 7 shows basic operating principle of 2/3 switched capacitor step down converter;

DESCRIPTION OF A PREFERRED EMBODIMENT

- It should be appreciated that the system in principle can be adapted to any input and
25 output voltages and still have the same advantages as in the specific example. The example shown is related to a battery powered headworn communication device, and more specifically to a hearing aid or a headset.

- The SC step down converter provides a power efficient conversion of the battery voltage
30 by a factor of e.g. 2/3 while the linear regulator ensures operation of the digital supply at low battery voltages. This technique as explained in the following allows significant saving of battery current compared to a supply based on a pure linear regulator.

The (high) battery voltage should power efficiently be transformed to a pre-defined lower supply voltage, which can be provided by a SC step down converter. This SC-power converter can however not guarantee sufficient output voltage at a low battery supply. A combination of a linear and a switched capacitor supply is therefore proposed
 5 here, where at low battery voltage the linear regulator gradually takes over the load current while maintaining the required supply voltage.

FIG. 1A shows the block diagram of the proposed supply FIG. 1B shows a simplified equivalent model. It consists of a 2/3-switched capacitor step down converter plus a
 10 linear regulator, which are connected in parallel. The switched capacitor part, whose detailed operation will be described later, can be considered as an ideal transformer applied to the battery with turn ratio $n=2/3$ and an equivalent resistor R_{sc} . On the other hand, the linear regulator can be seen as fixed voltage source V_{ref} with a (low-impedance) output resistance R_{lin} . When connected in parallel, both of the two parts contribute to the
 15 overall load current $I_L = I_{sc} + I_{lin}$ with decreasing current I_{lin} (linear regulator) for an increasing battery voltage V_{bat} . Above a critical battery voltage $V_{bat,crit}$, I_{lin} becomes zero and the load will only be supplied by the switched capacitor part. The advantage of such a combined scheme is that for battery voltages around $V_{bat,crit}$ a power supply is provided by a high efficient DC/DC converter while the linear regulator guarantees a certain
 20 minimum voltage $V_o = V_{ref}$. At battery voltages higher than $V_{bat,crit}$ the good efficiency is preserved, however, the output voltage is linearly increased due to the aforementioned transformer characteristics. For some applications, this might not be desired. A slightly more complex system, which automatically adapts the frequency dependent equivalent output resistance R_{sc} of the SC-regulator to the actual load, can maintain good efficiency
 25 while keeping the output voltage constant. This is described later.

The DC transfer characteristics of the described combined digital supply is shown in FIG. 2. These are based on a simulation using the schematic of FIG. 1 with ideal
 30 switches, capacitors and resistors.

As already mentioned above, the operation of the proposed SC-digital supply can be divided in two operation modes (reference is made to FIG. 3):

Mode 1: $V_{bat} > V_{bat,crit}$: Only switched capacitor is active. Output voltage V_o scales linearly with supply voltage

Mode 2: $V_{bat} \leq V_{bat,crit}$: Both linear and switched capacitor part are active. Output voltage V_o is constant around V_{ref} .

5 For $R_{lin} \rightarrow 0$ the DC characteristics can be described as follows:

Mode 1 ($V_{bat} > V_{bat,crit}$)

$$(1) \quad V_o = \frac{2}{3} \cdot V_{bat} \cdot \frac{R_L}{R_L + R_{SC}}$$

Mode 2 ($V_{bat} \leq V_{bat,crit}$)

$$10 \quad (2) \quad V_o = V_{ref}$$

$$(3) \quad I_{bat} = I_{bat,sc} + I_{bat,lin} = \frac{1}{R_{SC}} \left[V_{ref} \left(\frac{1}{3} + \frac{R_{SC}}{R_L} \right) - V_{bat} \cdot \frac{2}{9} \right]$$

$$(4) \quad I_{bat,sc} = \frac{2/3}{R_{SC}} \cdot \left[\frac{2}{3} \cdot V_{bat} - V_{ref} \right]$$

$$(5) \quad I_{bat,lin} = \frac{1}{R_{SC}} \left[V_{ref} \cdot \left(1 + \frac{R_{SC}}{R_L} \right) - \frac{2}{3} \cdot V_{bat} \right]$$

15 Where I_{bat} is the overall battery current, $I_{bat,sc}$ is the battery current contribution of the switched capacitor part and $I_{bat,lin}$ is the current contribution of the linear regulator.

The critical battery voltage $V_{bat,crit}$ (see FIG. 2) can be derived from equation (5) when setting $I_{bat,lin}$ to zero:

$$20 \quad (6) \quad V_{bat,crit} = V_{ref} \cdot \frac{3}{2} \left(1 + \frac{R_{SC}}{R_L} \right)$$

The above equations can be used to dimension the SC-digital supply such that its overall efficiency is optimal. The most critical parameter hereby is the knee-point at $V_{bat} = V_{bat,crit}$.

Above this voltage the linear regulator is inactive and the overall efficiency is maximum.

25 $V_{bat,crit}$ should be centered around the typical battery voltages, which can vary from battery type to battery type.

If desired, the supply may be configured such that it provides good power efficiency over a wide range of load currents, (which might change dynamically during lifetime of the battery) , whereby the above system can be made more flexible. In principle, this can be done by adapting R_{sc} the same amount as the load resistor changes, as the critical battery voltage $V_{bat,crit}$, where efficiency is best, depends on the load resistor R_L and the switched capacitor resistor R_{sc} . To keep $V_{bat,crit}$ to be at the optimum independent of the load current, the impedance R_{sc} can be changed by setting the clock frequency f_{sc} appropriate. As an example, one can say: if the load current is doubled, the clock frequency f_{sc} should also be doubled, which then effectively reduces R_{sc} by a factor two.

By measurement in the system which tells us whether the supply block operates close to optimum or not the frequency dependent sc-resistor R_{sc} may be changed, such that this optimum is achieved.

FIG. 3 depicts a scheme, which provides this information. The top graph shows the output vs. battery voltage whereas the bottom graph depicts the current delivered by the linear regulator. There are three regions of operation. In region 1 the sc-resistor R_{sc} is too high such that current partly has to be provided by the linear regulator. Region 2 is optimal since there is no linear current and the output voltage is close to the target voltage V_{ref} . In region 3, however, the impedance R_{sc} is too low, leading to an (undesirable) increase of the output voltage. The distinguishing of the three regions can be done by voltage and current comparators:

Voltage comparator for regions 2 and 3: provides a logic high if $V_o < V_{ref} + \Delta V$,

Current comparator for regions 1 and 2: provides a logic high if $I_{lin} < I_{lin, min}$.

By using the signals provided by these two comparators, a feedback loop may be provided in the system, which automatically changes R_{sc} through the clock frequency f_{sc} . An implementation of such a feedback loop is shown in FIG. 4. If the current comparator goes high (R_{sc} too low), R_{sc} will be increased. The effect then is that the system may slowly oscillate between the borders of the good region (2), depending on the load. Time

constant of the oscillation is set by the decoupling capacitor C_L , the load R_L and the sc-resistor R_{sc} .

As an example, FIG. 5 shows a behavioural simulation of this adaptive system, when a load current is applied. The bottom trace of the figure shows the output voltage oscillating within a small ripple around V_{ref} . The transient battery current, shown in the third trace, jumps between the two current levels defined by the sc-resistor R_{sc} . In the top part of the figures the waveforms of the two comparators are shown, indicating in which region of operation the system is working (see explanation above).

FIG. 6 shows simulation results using a full transistor level schematic for the regulator system. Top trace is the output voltage for load currents varying between 180 μ A ...500 μ A. In the middle trace the efficiency is plotted, both for the adaptive and the non-adaptive voltage supply. In the lower trace the oscillation frequency of the aforementioned ripple is shown, appearing between 300 μ A ...400 μ A of load current.

To understand the basic operating principle of the 2/3 switched capacitor DC/DC converter, FIG. 7 provides some background. The switched capacitor circuit is periodically switched back and forth between the two phases (ϕ_2) "charge phase" and (ϕ_1) "dump phase", from which FIG. 7 shows the transient between ϕ_2 to ϕ_1 . In the charge phase, both capacitors C_1 are configured in parallel and put in series to the load capacitor C_L . Charge is flowing from the battery to both C_1 and C_L and the output becomes $V_{o1-} = V_{bat} - V_{11-}$, where V_{11-} is the voltage across C_1 . In the dump phase, the capacitors C_1 are configured in series to the load capacitor C_L , in order to arrive at $V_{o1+} = 2 * V_{11+}$. In no load condition ($I_L = 0$) the output voltage does not change from phase to phase, hence $V_{o1+} = V_{o1-}$ and $V_{11+} = V_{11-}$. This can only be satisfied for V_o being exactly $2/3 * V_{bat}$.

When a load current I_L is applied to the 2/3 SC-DC/DC converter, the settled output voltage V_o no longer is exactly $2/3 * V_{bat}$ and a voltage pattern as shown in the bottom of FIG. 7 is achieved. It can be shown that for large load caps $C_L \gg C_1$, the following expression for the output voltage may be used:

$$(7) \quad V_0 = \frac{2}{3} \cdot V_{bat} - R_{sc} \cdot I_L$$

- where $f_{sc}=1/T$ is the switching frequency and R_{sc} is the equivalent switched capacitor
 5 impedance of the 2/3 converter. The voltage ripple $\Delta V=V_{o1+}-V_{o1-}$ can be determined to be
 proportional to R_{sc} and the load current I_L ($C_L \gg C_1$):

$$(8) \quad \Delta V \propto R_{sc} \cdot I_L$$

CLAIMS

1. A method for conversion of a battery voltage in a battery powered headworn communication device, the method comprising providing a voltage reduction to a
5 fixed part of the input voltage and providing a variable reduction that ensures that a minimum voltage is maintained.
2. A method according to claim 1, where the fixed part reduction and the variable reduction are performed in parallel.
- 10 3. A method according to claim 1 or 2, where the fixed voltage conversion is a $2/3$ conversion of the input voltage.
4. A method according to claim 1, 2 or 3, where a fixed voltage conversion and the
15 variable voltage conversion are balanced according to the actual battery voltage.
5. A method according to any of the preceding claims, where a switched capacitor resistance is controlled by setting the clock frequency of a switched capacitor voltage reduction system.
- 20 6. A battery powered headworn communication device comprising a voltage conversion system for converting the battery voltage, the voltage conversion system comprising means for providing a voltage reduction to a fixed part of the input voltage and in addition to this means for providing a variable reduction that
25 ensures that a minimum voltage is maintained.
7. A battery powered headworn communication device according to claim 6, where fixed part voltage reduction means and the variable reductions means are arranged in parallel.
- 30 8. A battery powered headworn communication device according to claim 6 or 7, where the means for providing a voltage reduction to a fixed part of the input voltage comprises a switched capacitor conversion element.

9. A battery powered headworn communication device according to claim 6, 7 or 8, where the switched capacitor conversion element is adapted to perform a $2/3$ conversion of the input voltage.

5

10. A battery powered headworn communication device according to any of the preceding claims, where the means for providing a voltage reduction to a fixed part of the input voltage and the means for providing a variable reduction that ensures that a minimum voltage is maintained are balanced according to the actual battery voltage.

10

11. A battery powered headworn communication device according to claim 10, where the switched capacitor resistor balanced in relation to the load current by controlling the switched capacitor system frequency.

15

12. A hearing aid operating at a voltage lower than the battery voltage, where a voltage conversion system is implemented, where the voltage conversion system comprises the elements according to any of the preceding claims.

20

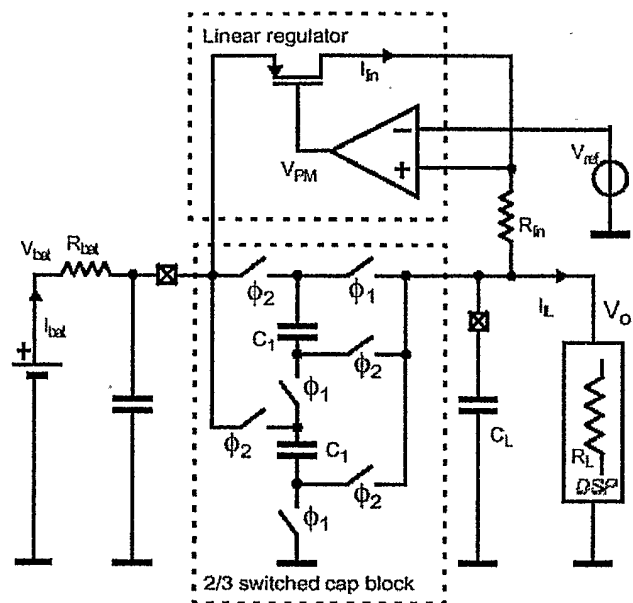


FIG. 1A

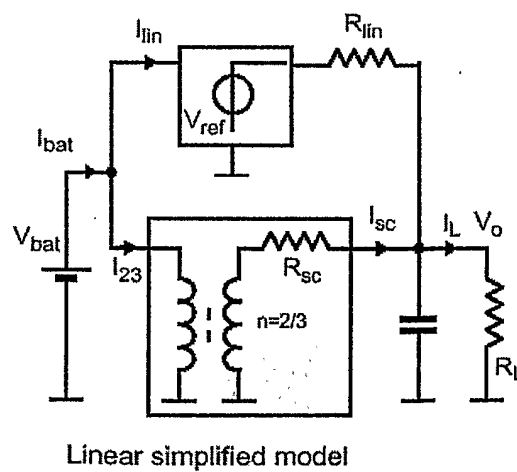


FIG. 1B

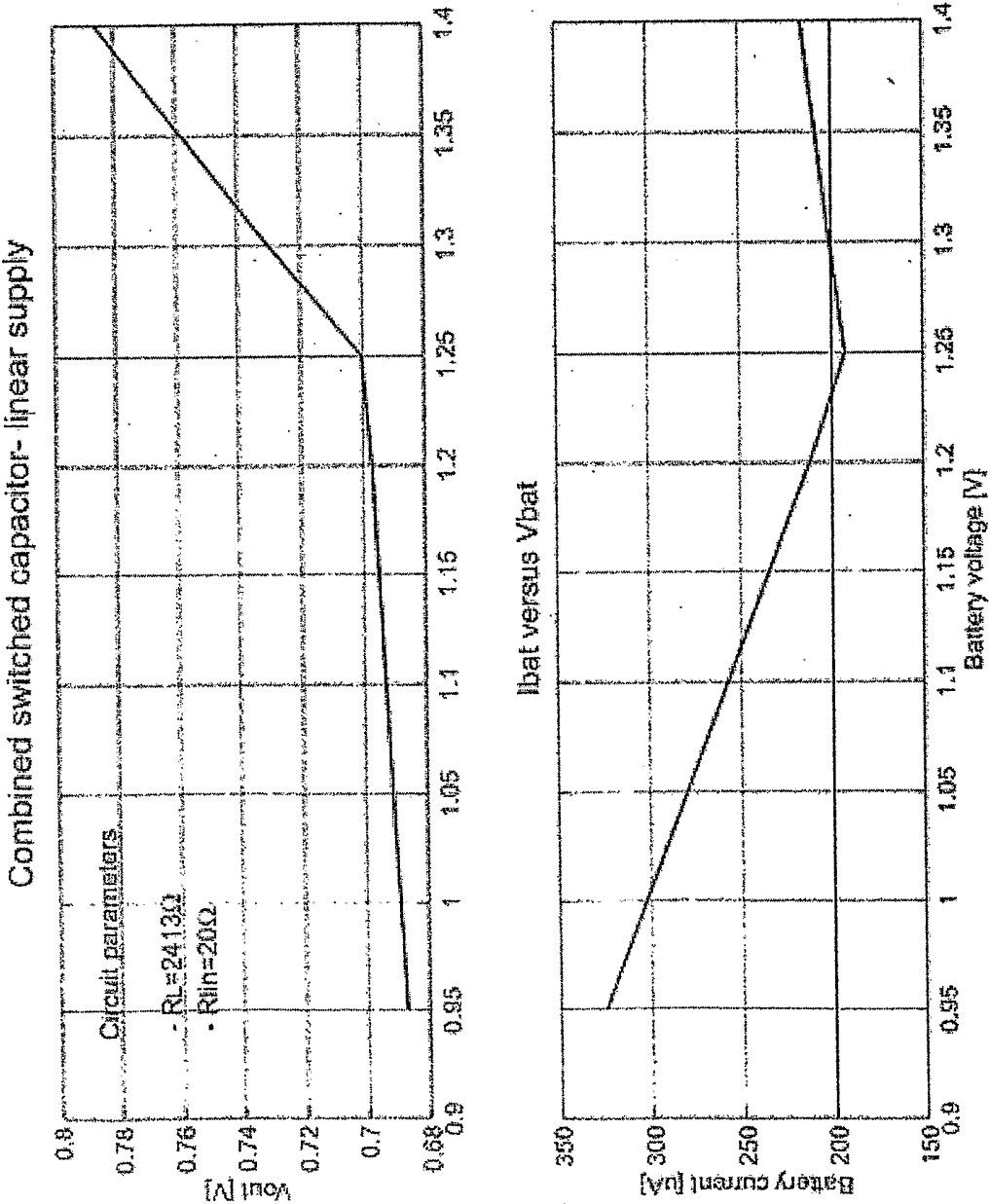


FIG. 2

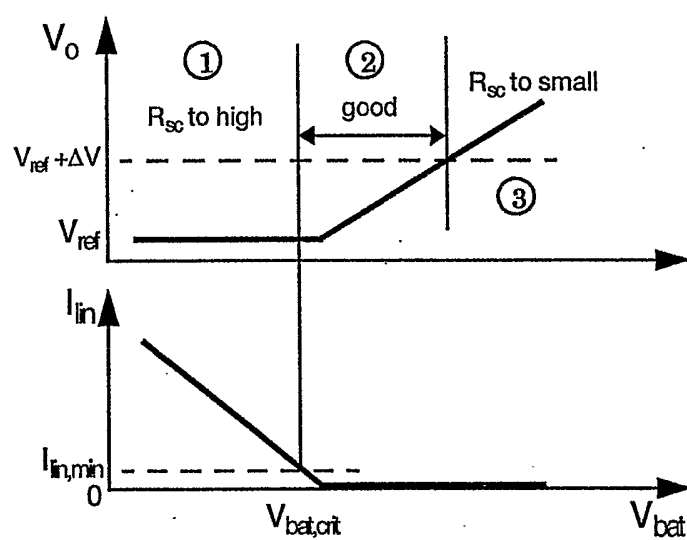


FIG. 3

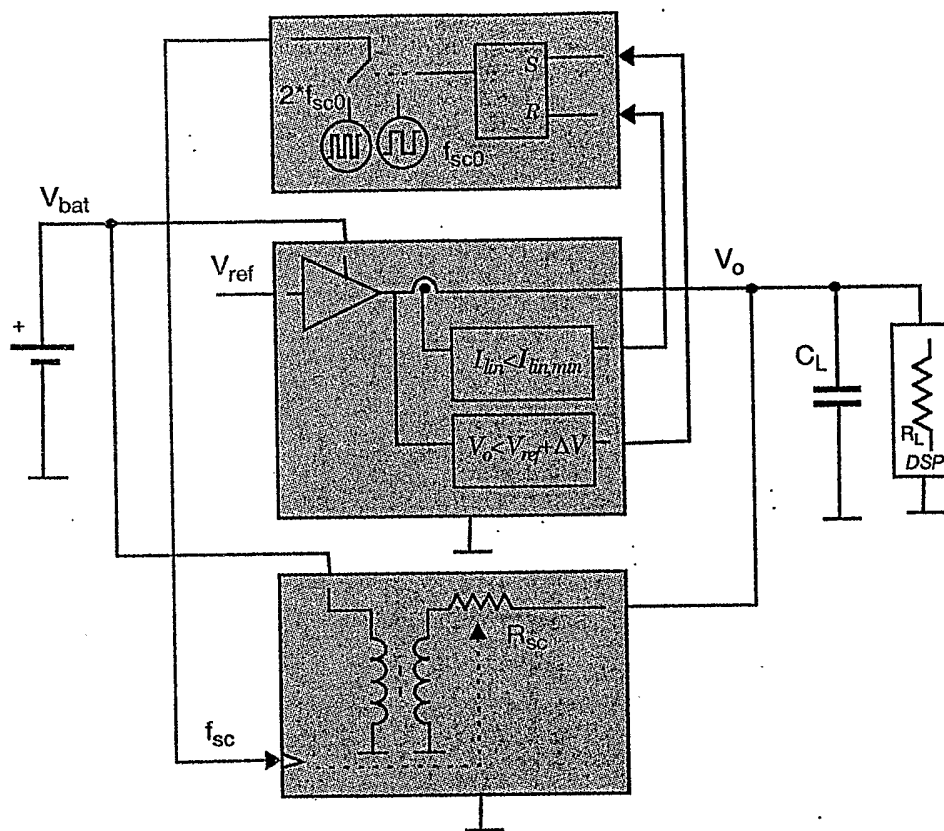


FIG. 4

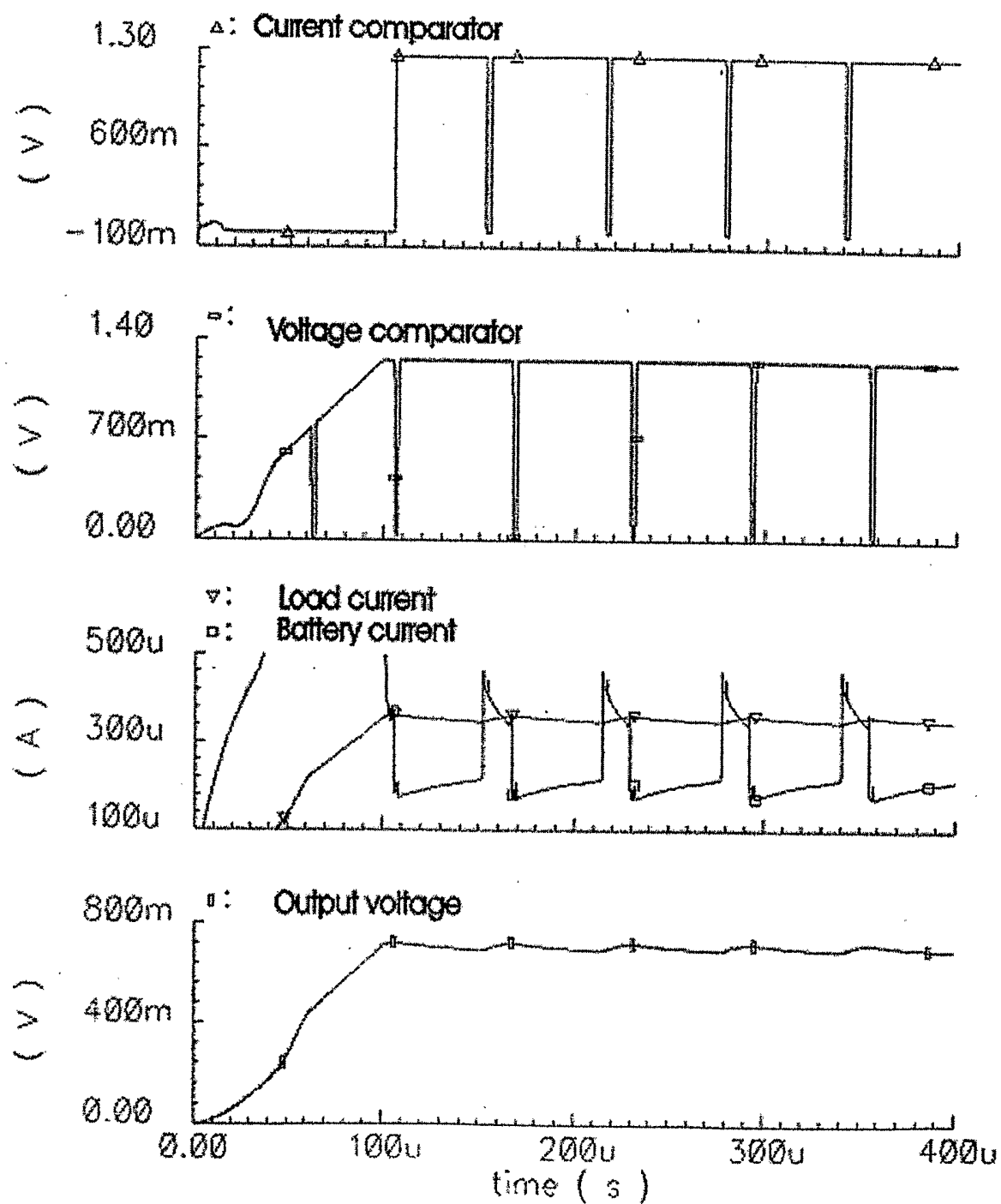


FIG. 5

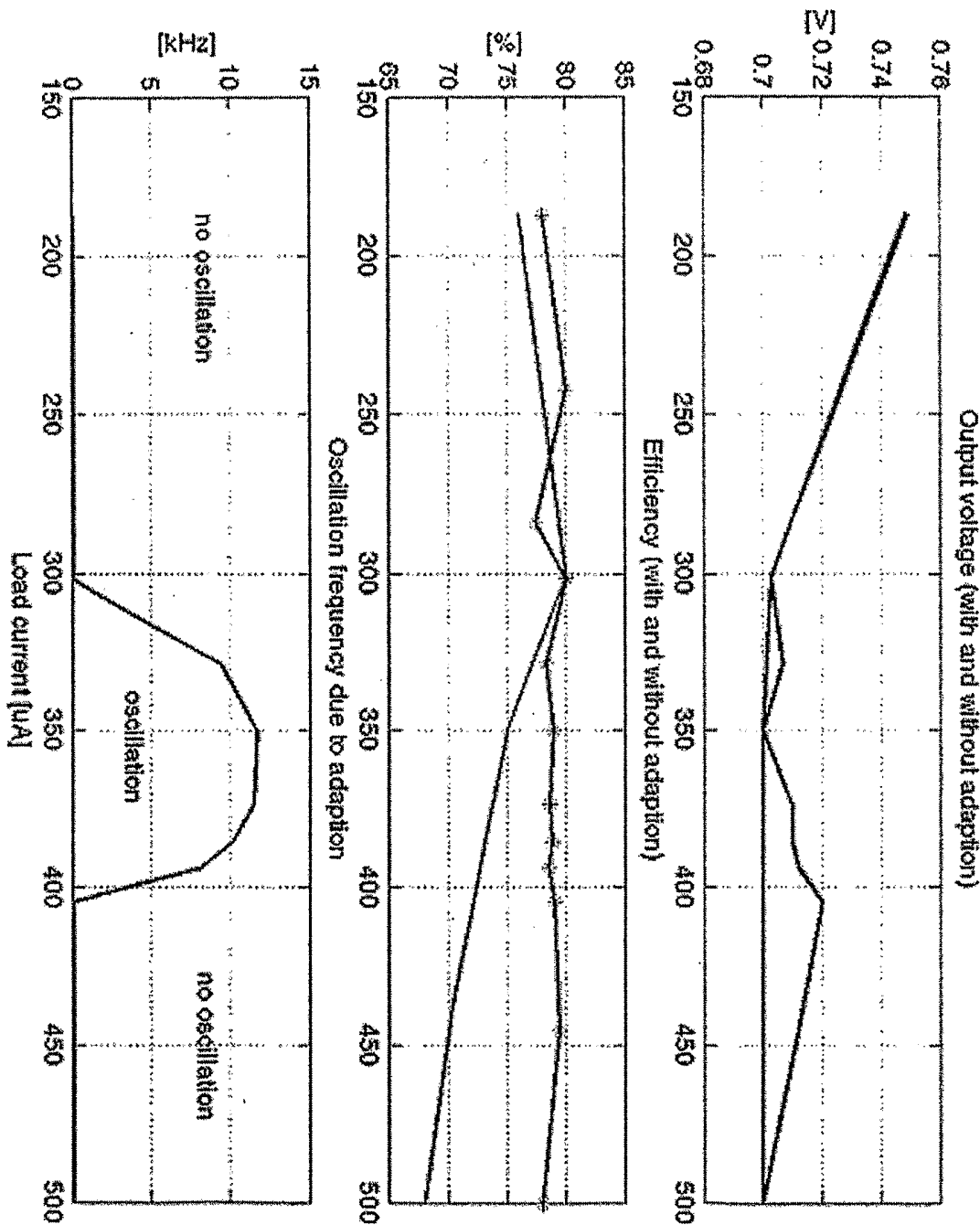
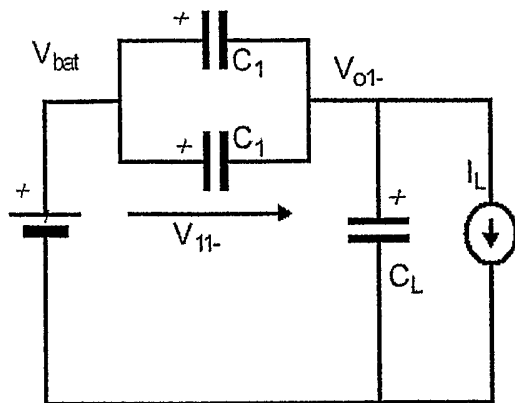
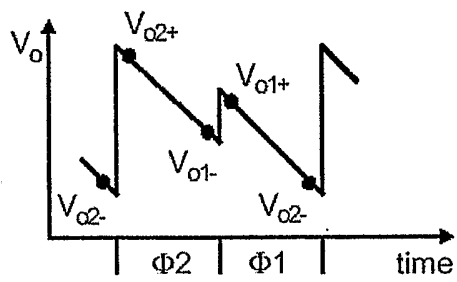
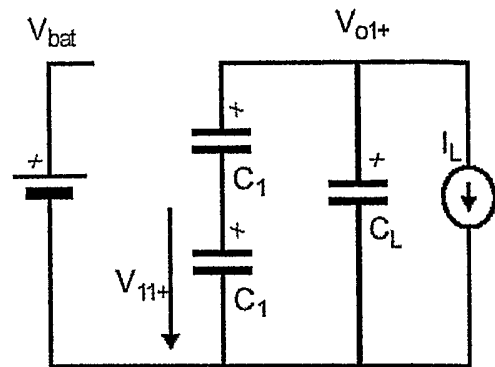


FIG. 6

Phase $\Phi 2$ (charge phase)



Phase $\Phi 1$ (dump phase)



Voltage ripple $\Delta V = V_{o2+} - V_{o2-}$

FIG. 7

INTERNATIONAL SEARCH REPORT

International Application No.

PCT/EP 03/05558

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 H02M3/07 G05F1/10 H04R1/04

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)

IPC 7 H02M G05F H04R H02J H03K

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 practical, 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	EP 0 610 939 A (NIPPON ELECTRIC CO) 17 August 1994 (1994-08-17) page 9, line 50 -page 10, line 25; figures 4A,7A	1,2,4, 6-8,10, 12
X	US 4 868 908 A (RYAN JOHN G ET AL) 19 September 1989 (1989-09-19) the whole document	1-12
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A	US 4 509 193 A (CARLSON ELMER V) 2 April 1985 (1985-04-02) abstract; figure 2	1-12

☐

Further documents are listed in the continuation of box C.

☒

Patent family members are listed in annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *G* document member of the same patent family

Date of the actual completion of the international search

13 August 2003

Date of mailing of the international search report

02/09/2003

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Braccini, R

Continuation of Box I.2

The initial phase of the search revealed a very large number of documents relevant to the issue of novelty. So many documents were retrieved that it is impossible to determine which parts of the claims may be said to define subject-matter for which protection might legitimately be sought (Article 6 PCT). For these reasons, a meaningful search over the whole breadth of the claim(s) is impossible. Consequently, the search has been restricted to:

The methods/apparatus mentioned in the description at pages 4 to 6.

The applicant's attention is drawn to the fact that claims, or parts of claims, relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure.

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/EP 03/05558

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
see FURTHER INFORMATION sheet PCT/ISA/210

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International Application No.

PCT/EP 03/05558

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