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(54) **SYNCHRONIZED CONTROLLED OSCILLATION MODULATOR**

SYNCHRONISIERTER GESTEUERTER OSZILLATIONSMODULATOR

MODULATEUR OSCILLANT A COMMANDE SYNCHRONISE

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Description

Technical field

[0001] This invention relates to a self-oscillating modulator, comprising a comparator and a power amplification stage for pulse width modulation, and higher order oscillating loops comprising first feedback means and first forward means securing stable oscillating conditions.

[0002] The invention also relates to a switching power conversion system, such as DC-AC (e.g. audio amplification), DC-DC or AC-AC conversion systems or any combination of the above mentioned comprising such a modulator. The invention may advantageously be used for improved power conversion in any system, in particular precision DC-AC conversion systems such as high efficiency audio amplification.

Technical background

[0003] The pulse width modulator is a central element of any power conversion system. Most switching power converters are based on Pulse Width Modulation (PWM) as means to control efficient conversion between domains (DC or AC).

[0004] A typical power converter may include a PWM modulator, a switching power conversion stage, a filter and a control system. A prior art system of this type is described in US Patent. No. 4724396 and by Mr. Attwood in Journal of the AES, Nov. 1983. p. 842-853. However, PWM has a range of shortcomings also well known to the art, mainly due to the implementation of the carrier generation. This limits the system bandwidth and complicates design. Also, a stable and robust control system design is difficult.

[0005] In order to overcome these drawbacks, a controlled oscillating modulator (COM) was introduced in the applicant's international patent application PCT/DK97/00497, published as WO98/19391. The disclosed modulator eliminates the need of a carrier generator, with a range of advantages, described in detail in said document.

[0006] A problem with this technique is that it can only synthesize standard two level modulation - hence giving disadvantages concerning the efficiency of the amplifier.

[0007] Another problem arises in multi channel systems such as multi channel audio amplifiers, the oscillating modulators will have oscillation frequency variations, which will cause intermodulation products, adding distortion components within the audio bandwidth. A prior art system for synchronizing an oscillating modulator to an external clock is given in US patent no. US 6,297,693. This prior art system can only comprise a sawtooth or a triangular signal shape as synchronization signal eliminating possibilities to use COM modulator signals as synchronization signals. Furthermore the system can only synchronize a modulator to an external clock leading to higher complexity when implementing an external clock generator.

[0008] In multilevel systems such as, but not limited to PSCPWM systems (as described in applicants international patent application WO00/33448, the first harmonic of the carrier is not present at the output, and said COM modulator can thereby not be used.

Objects of the invention

[0009] Accordingly, an object of the invention is to provide a superior modulation technique in switching power conversion systems that overcomes fundamental problems related to conventional techniques.

Summary of the invention

[0010] These objects are achieved by a novel synchronized controlled oscillating modulator (SCOM) of the type mentioned above, having synchronizing means connected to said COM modulator.

[0011] The invention provides significant advantages in performance, topological simplification, improved robustness, stability and efficiency compared to prior art.

[0012] The invention provides synchronization between a plurality of COM modulators and a signal source or between a plurality of COM modulators in order to overcome prior art problems related to COM modulators being desynchronized.

[0013] The COM modulators can comprise voltage or current measurement means, and feedback.

[0014] The synchronization means can use an external source as synchronization signal, where the external source can preferably but not necessarily be a triangular-, square- or sinusoidal signal.

[0015] Alternatively, the modulator comprises several COM modulators, and the synchronizing means are arranged between the COM systems, so that the oscillation modulator signal is used as synchronization signal. In this case, the SCOM aims to combine the advantages of the COM technology with the advantages of multi-level PWM.

[0016] According to this embodiment, pulse modulation in general power conversion systems is provided that implements multiple level pulse modulated signals - hence reducing the output switching noise energy and enhancing the possibilities for control system implementation.

[0017] The SCOM modulator according to the invention is very suitable in all types of precision DC-AC conversion applications as audio amplification and motor or electrodynamic transducer drive applications.

[0018] The SCOM can advantageously be used in precision voltage or current controlled DC-AC conversion as e.g. power amplifiers for audio use.

[0019] The power amplification stage can comprise an output filter, and the second feedback means can then be connected to an output from said output filter. This permits a first filtering of the voltage before it is fed back in the feedback path.

Brief description of the drawings

[0020] Preferred embodiments of the present invention will be further described in the following, with reference to the appended drawings.

Fig. 1 illustrates a prior art controlled oscillating modulator based on voltage feedback.
Fig. 2 illustrates a prior art controlled oscillating modulation system comprising current feedback.
Fig. 3 illustrates a block diagram of a synchronized modulator.
Fig. 4 illustrates a block diagram of a 3-level modulator according to the invention.
Fig. 5 illustrates a hardware implementation of the synchronization means in fig 3 and 4.
Fig. 6 illustrates a further embodiment of the invention for active synchronization of COM modulators.
Fig. 7 illustrates an implementation of the active synchronization in fig 6.
Fig. 8 illustrates a power conversion system with two COM modulators, synchronized according to the invention.
Fig 9 illustrates the open loop gain of the system in Fig. 8.
Fig. 10 illustrates an implementation of a synchronization according to the invention in a PSCPWM modulator structure.
Fig. 11 illustrates a plurality of N (where N is an integer) COM modulators synchronized by an additional synchronization signal.
Fig. 12 illustrates a plurality of N (where N is an integer) COM modulators synchronized by their common COM signals.

Detailed description of the preferred embodiments

[0021] In the following detailed description of the preferred embodiments, the COM modulators can be Voltage Controlled Oscillating Modulators (fig 1) as described in the applicant's international patent application PCT/DK97/00497 or Current Controlled Oscillating Modulators (fig 2) as described in the applicants Swedish patent application with application no. 0003342-3 and in US 6 362 702.

[0022] A power conversion system comprising a modulator is shown in fig. 3. The system comprises a power stage 2, a control system with a feedback block 3 and a forward block 4. The power stage 2 can comprise one or a plurality of half-bridges, preferably a full-bridge comprising two half-bridges. The feedback block and the forward block constitute an oscillating modulator 5. An external signal source 1, also referred to as an oscillating signal generator block, is connected to a synchronization block 6 in the modulator 5.

[0023] The synchronization of the modulator 5 is obtained by adding the Osc Signal from the source 1 to the modulating signal. The synchronization signal can be based on a voltage signal or a current signal depending on the type of modulator (voltage based feedback or current based feedback). The Osc Signal can be a sinusoidal signal or any other oscillating signal with the frequency of the wanted idle switching frequency and is used for synchronizing said modulator with said Osc signal of the Osc Signal generating block 1.

[0024] An embodiment of the invention is shown in fig. 4, where two COM modulators 10, 11 are synchronized by one synchronizing signal from a synchronization block 12. Again, the synchronization signal can be based on a voltage signal or a current signal depending on the type of modulator (voltage based feedback or current based feedback).

[0025] The two COM modulators are designed to oscillate at almost the same frequency, but a variation in the switching frequency can be eliminated by the synchronization means.

[0026] By the use of two COM modulators 10, 11 it is possible to make a 3-level modulator. Each side of a load 13 is supplied with its own 2-level COM modulator 10, 11, which each are synchronized.

[0027] The first harmonic of the carrier will ideally be eliminated across the load. The input signal is inverted by an inverter 14 preceding the second COM 11, in order to be able to make a differential audio signal on the output. The spectral characteristics resemble those of the NBDD modulation. The NBDD can be seen from "Audio power amplifier techniques with energy efficient power conversion", Ph.D Thesis by Karsten Nielsen.

[0028] The use of said 3-level modulation can advantageously be used for driving a pulse modulated transducer directly without any output filtering of the PWM signal thus reducing eddy current losses in the transducer 6 compared to a 2-level modulation.

[0029] Fig 5 shows an example of a realization of the synchronizing means in figs 3 and 4. The synchronization means are implemented as a circuit of two series resistances RA, RB connected to each end of a parallel circuit consisting of a resistor ROSC and a capacitor COSC.

[0030] By the use of this network a small amplitude signal is added to the COM modulator forcing the COM modulator to oscillate at the added small amplitude signal frequency. Thereby one or a plurality of COM modulators can be synchronized by adding a small amplitude signal with the frequency of the wanted idle frequency to each of the modulators.

[0031] The values of the resistances and capacitors can be determined by the skilled person in a trade-off between having good synchronization and not having to influence either of the modulators negatively.

[0032] A further preferred embodiment of the invention is shown in Fig. 6 and illustrates an active synchronization system for obtaining synchronization of COM modulators. The active synchronization block 15 comprises one or a plurality active high pass filters.

[0033] Fig. 7 gives an example of the active synchronization block 15 in fig 6, implemented as two active high pass filters 16, 17. One high pass filter 16 sums a first high pass filtered COM modulator signal at node 18 to a second COM modulator signal at node 19 and thereby synchronizes the second COM modulator with the first. The optimal synchronization will be obtained if also a second high pass filter 17 sums a high pass filtered second modulator signal at node 19 to the first modulator signal at node 18.

[0034] A power conversion system with two COM modulators, synchronized according to the invention, is shown in Fig. 8. Two lag-blocks B1, B2 are inserted in the forward path contributing to a higher loop gain at low frequencies. There is not any high power filtering applied to the system but the load, preferably an electro-dynamic transducer, will act as an inductive load obtaining some filtering of the PWM signal. Thereby the output filter can be eliminated and efficiency increased. Each power stage 20, 21 can comprise one or a plurality of half-bridges, and preferably comprise a single half-bridge.

[0035] The open loop gain for the system in Fig. 8 is shown in Fig. 9. The system is designed for a switching frequency of approximately 325kHz. At 325kHz the open loop gain is 0 dB and at that frequency the phase is -180 degrees, obtaining a controlled oscillation. The system shown in Fig. 8 will be capable of suppressing noise and distortion within the 325kHz bandwidth.

[0036] The system output is a differential 3-level PWM signal with high frequency spectral characteristics resembling those of the NBDD modulation obtaining a more efficient modulation compared to modulation topologies with a differential two level PWM output signal.

[0037] If the modulators in the system shown in Fig. 9 are completely synchronized, there will be a differential output of zero magnitude at idle. This is caused by the signal at idle on one terminal 22 of the load is equal to the signal on the other terminal 23 of the load obtaining a differential signal of zero magnitude.

[0038] The synchronization can be obtained by synchronization means as shown in fig 5, as a synchronization network comprising an R, C or RC circuit. The R, C or RC circuit being connected to the comparator in the forward path. The synchronization can also be obtained as in fig 6 and 7, as an active network comprising high pass active filter networks.

[0039] Furthermore the modulation depth can be controlled by limiting the amplitude of the input signal at the input signal node 24, achieving lower ripple currents.

[0040] Fig. 10 shows an SCOM according to the invention implemented in multilevel PWM comprising a PSCPWM modulator structure and a MECC(N,M) control system where N,M are integers. MECC(N,M) is described in the applicant's international patent application PCT/DK97/00497. The system comprises one or a plurality of feedback paths and low pass filtering of the output PWM signal 25, 26. With the SCOM system comprising a PSCPWM modulator it is possible to obtain a multi-level (more than two levels) modulator, preferably without high frequency common mode components on the output. Each power stage 27, 28 comprises one or a plurality of half-bridges. If each power stage 27, 28 comprises two half-bridges in a full-bridge structure it is possible to obtain a multi-level (more than two levels) modulator, without high frequency common mode components on the output.

[0041] In fig 11, N (where N is an integer) SCOM modulators are synchronized by an additional synchronization signal. This synchronization signal can be any signal shape but preferably triangular, square or sinusoidal with a frequency of the wanted idle switching frequency. The synchronization means can be any one of those described above.

[0042] In Fig. 12, N (where N is an integer) COM modulators are synchronized by their common COM signals. The common COM synchronization signal can be any signal shape with the frequency of the wanted idle switching frequency. The synchronization means can be any one of those described above.

[0043] The SCOM modulator can be implemented in any given AC-AC, DC-DC, AC-DC or DC-AC power conversion system, in particular a high precision DC-AC audio power conversion system where the power stage elements operates in either "on" or "off" state.

Claims

1. A synchronized controlled oscillation modulator, comprising

    at least a first and a second controlled oscillation modulators (COMs) (5; 10) each having a power stage (2) and higher order oscillating loops comprising a first feedback block (3) and a first forward block (4) securing stable oscillating conditions, and
    synchronizing means (1, 6; 12; 15) connected between forward paths of said first and second COM modulators (10, 11) and arranged to synchronize the first and second COM modulators (10, 11) with each other.

2. A modulator according to claim 1, wherein said synchronization means comprise a circuit consisting of resistors and/or capacitors.

3. A modulator according to claim 2, wherein said synchronizing means comprise:

    a first and a second series resistances (R_A, R_B),
    a parallel resistor (R_{OSC}), and
    a parallel capacitor (C_{OSC}),

    wherein said first series resistance is connected to a first end of the parallel capacitor and parallel re-

sistor, and said second series resistance is connected to a second end of the parallel capacitor and parallel resistor, and
wherein said first and second series resistances are connected to a comparator in the forward path of each modulator respectively.

4. A modulator according to claim 1, wherein said synchronization means (15) comprise an active circuit, preferably including at least one high pass filter.

5. A modulator according to claim 1, where the modulators are driven in a full-bridge configuration to achieve a three-level pulse output.

6. A modulator according to claim 5, implemented in a system without common mode high frequency spectral contributions in the three level output.

7. A modulator according to any of the preceding claims, implemented in a multi-loop feedback control system for enhanced noise suppression, having a number of local and global control loops respectively.

8. A modulator according to claim 1, comprising N COM modulators synchronized by an additional synchronization signal or by a common COM signal of said COM modulators.

9. A modulator according to any of the preceding claims, further comprising limiter means to control the PWM modulation depth.

10. A modulator according to any of the preceding claims implemented in a general power conversion system, in particular in DC-AC audio power conversion systems.

11. A modulator according to any of the preceding claims, used to drive an electrodynamic transducer load directly.

12. A modulator according to any of the preceding claims, said COM modulator comprising a comparator, a power amplification stage, and a negative feedback loop adapted to achieve conditions for controlled oscillation at a predetermined frequency.

Patentansprüche

1. Synchronisierter gesteuerter Oszillationsmodulator, der Folgendes umfasst:

mindestens einen ersten und einen zweiten gesteuerten Oszillationsmodulator (COMs) (5; 10), die jeder eine Leistungsstufe (2) und Oszillationsschleifen höherer Ordnung aufweisen, die einen ersten Rückkopplungsblock (3) und einen ersten Durchlassblock (4) umfassen, die stabile Oszillationsbedingungen sichern, und
Synchronisiermittel (1, 6; 12; 15), die zwischen Durchlasspfaden des ersten und des zweiten COM-Modulators (10, 11) angeschlossen und dafür geeignet sind, den ersten und den zweiten COM-Modulator (10, 11) miteinander zu synchronisieren.

2. Modulator nach Anspruch 1, wobei die Synchronisiermittel einen Schaltkreis umfassen, der aus Widerständen und/oder Kondensatoren besteht.

3. Modulator nach Anspruch 2, wobei die Synchronisiermittel Folgendes umfassen:

einen ersten und einen zweiten Reihenwiderstand (R_A, R_B),
einen Parallelwiderstand (R_{osc}), und
einen Parallelkondensator (C_{OSC}),

wobei der erste Reihenwiderstand mit einem ersten Ende des Parallelkondensators und des Parallelwiderstandes verbunden ist und der zweite Reihenwiderstand mit einem zweiten Ende des Parallelkondensators und des Parallelwiderstandes verbunden ist, und
wobei der erste und der zweite Reihenwiderstand jeweils mit einem Komparator in dem Durchlasspfad jedes Modulators verbunden sind.

4. Modulator nach Anspruch 1, wobei die Synchronisiermittel (15) einen aktiven Schaltkreis umfassen, der vorzugsweise mindestens ein Hochpassfilter umfasst.

5. Modulator nach Anspruch 1, wobei die Modulatoren in einer Vollbrückenkonfiguration angesteuert werden, um eine dreistufige Impulsausgabe zu erreichen.

6. Modulator nach Anspruch 5, der in einem System ohne Gleichtakt-Hochfrequenzspektralanteile in der dreistufigen Ausgabe implementiert ist.

7. Modulator nach einem der vorangehenden Ansprüche, der in einem Mehrschleifen-Rückkopplungssteuerungssystem für eine verbesserte Rauschunterdrückung implementiert ist, das eine Anzahl lokaler bzw. globaler Steuerungsschleifen aufweist.

8. Modulator nach Anspruch 1, der N COM-Modulatoren umfasst, die durch ein zusätzliches Synchronisationssignal oder durch ein gemeinsames COM-Signal der COM-Modulatoren synchronisiert werden.

9. Modulator nach einem der vorangehenden Ansprüche, der des Weiteren Begrenzermittel zum Steuern der Impulsbreitenmodulationstiefe umfasst.

10. Modulator nach einem der vorangehenden Ansprüche, der in einem allgemeinen Leistungswandlungssystem implementiert ist, insbesondere einem Gleichstrom-Wechselstrom-Audio-Leistungswandlungssystem.

11. Modulator nach einem der vorangehenden Ansprüche, der dafür verwendet wird, eine elektrodynamische Messwandlerlast direkt anzusteuern.

12. Modulator nach einem der vorangehenden Ansprüche, wobei der COM-Modulator einen Komparator, eine Leistungsverstärkungsstufe und eine negative Rückkopplungsschleife umfasst, die dafür geeignet ist, Bedingungen für eine kontrollierte Oszillation bei einer vorgegebenen Frequenz zu erreichen.

Revendications

1. Modulateur oscillant à commande synchronisée, comprenant

au moins un premier et un deuxième modulateurs oscillants (COMs) commandés (5 ; 10), ayant chacun un étage de puissance (2) et des boucles oscillantes d'ordre supérieur comprenant un premier bloc de rétroaction (3) et un premier bloc avant (4) assurant des conditions d'oscillation stables, et
des moyens de synchronisation (1, 6 ; 12 ; 15) connectés entre les trajets avant desdits premier et deuxième modulateurs COM (10, 11) et agencés afin de synchroniser le premier et le deuxième modulateur COM (10, 11) l'un avec l'autre.

2. Modulateur selon la revendication 1, dans lequel lesdits moyens de synchronisation comprennent un circuit constitué de résistances et/ou condensateurs.

3. Modulateur selon la revendication 2, dans lequel lesdits moyens de synchronisation comprennent :

une première et une deuxième série de résistances (R_A, R_B),
une résistance parallèle (Rosc), et
un condensateur parallèle (C_{OSC}),

dans lequel ladite première série de résistances est connectée à une première extrémité du condensateur parallèle et de la résistance parallèle, et ladite deuxième série de résistances est connectée à une seconde extrémité du condensateur parallèle et de la résistance parallèle, et
dans lequel lesdites première et deuxième séries de résistances sont connectées à un comparateur dans le trajet avant de chaque modulateur respectivement.

4. Modulateur selon la revendication 1, dans lequel lesdits moyens de synchronisation (15) comprennent un circuit actif, de préférence incluant au moins un filtre passe haut.

5. Modulateur selon la revendication 1, dans lequel les modulateurs sont entraînés dans une configuration en pont complète afin d'obtenir une sortie d'impulsions à trois niveaux.

6. Modulateur selon la revendication 5, implémenté dans un système sans contributions spectrales haute fréquence en mode commun dans la sortie à trois niveaux.

7. Modulateur selon une quelconque des revendications précédentes, implémenté dans un système de commande à rétroaction multi-boucles à des fins de suppression de bruit améliorée ayant un certain nombre de boucles de commande locales et globales respectivement.

8. Modulateur selon la revendication 1, comprenant N COM modulateurs synchronisés par un signal de synchronisation additionnel ou par un signal COM commun desdits modulateurs COM.

9. Modulateur selon une quelconque des revendications précédentes, comprenant en outre des moyens de limiteur pour commander la profondeur de modulation d'impulsions en largeur.

10. Modulateur selon une quelconque des revendications précédentes implémenté dans un système de conversion de puissance général, en particulier dans des systèmes de conversion de puissance audio DC-AC.

11. Modulateur selon une quelconque des revendications précédentes, utilisé pour entraîner directement une charge de transducteur électrodynamique.

12. Modulateur selon une quelconque des revendications précédentes, ledit modulateur COM comprenant un comparateur, un étage d'amplification de puissance et une boucle de rétroaction négative adaptés afin d'obtenir des conditions d'oscillation contrôlée à une fréquence prédéterminée.

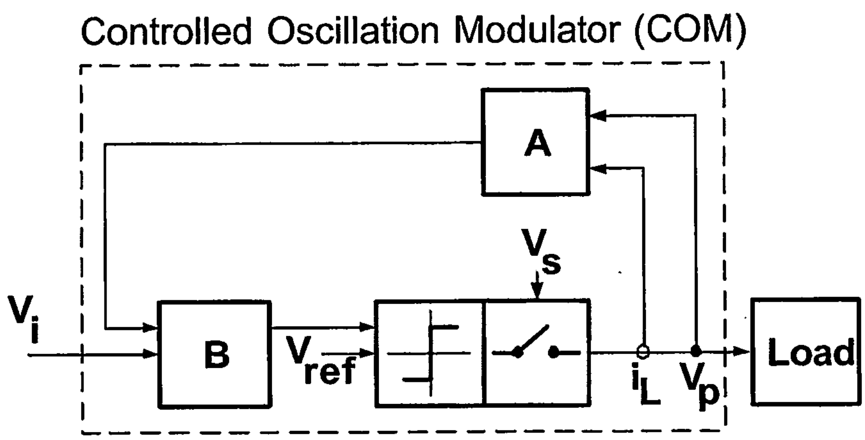

Fig. 1 (Prior art)

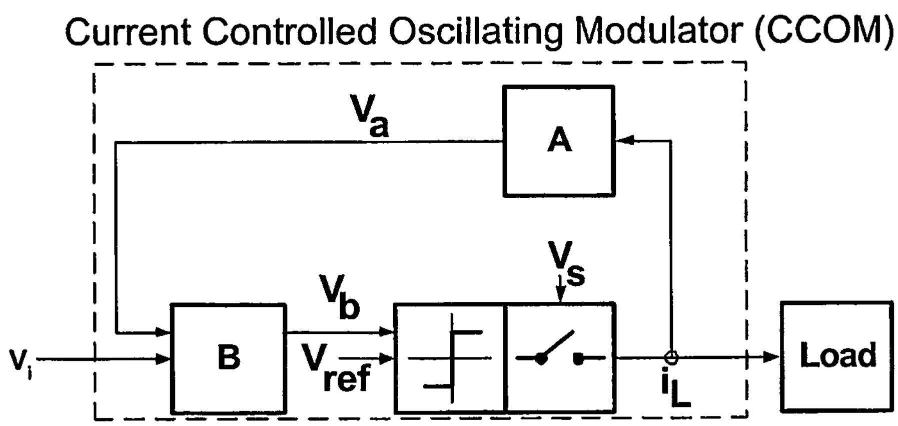

Fig. 2 (Prior art)

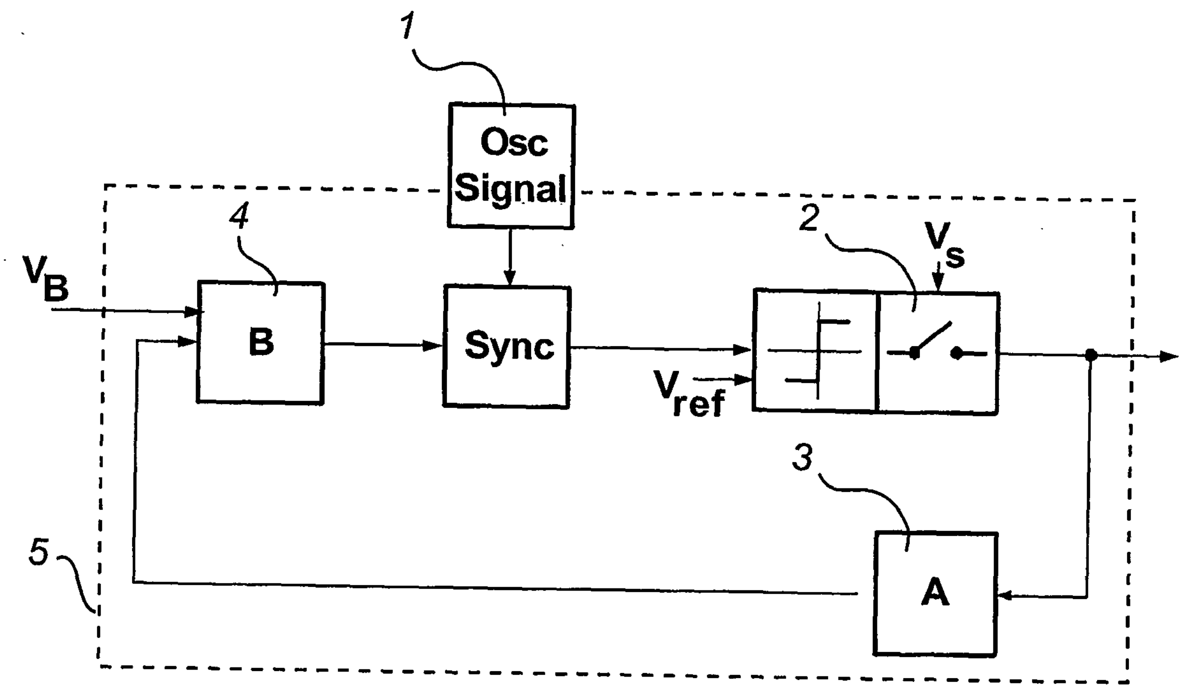
1
Osc
Signal
4
VB
B
Sync
2
Vs
Vref
3
A
5

Fig. 3

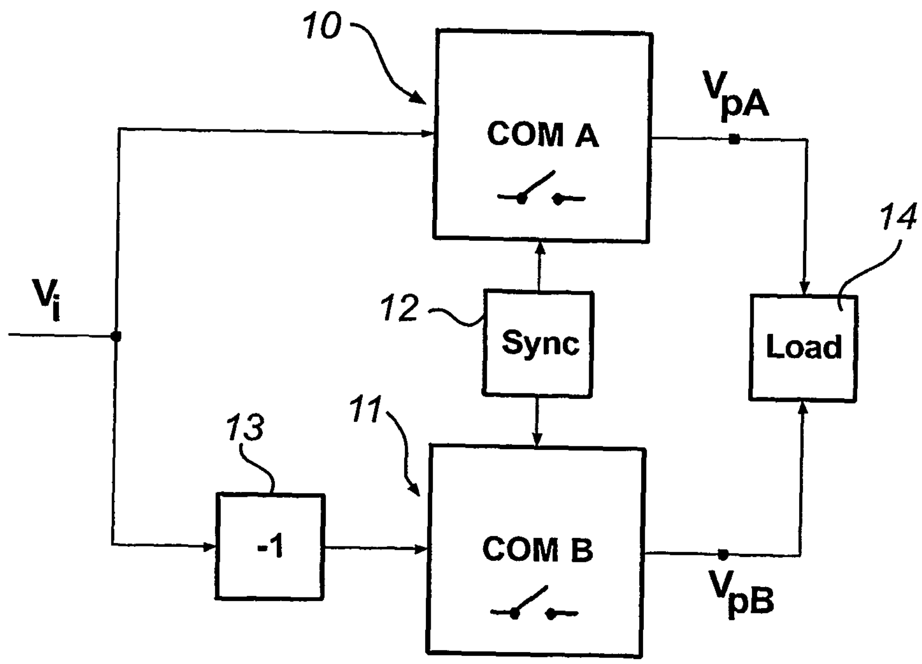
10
COM A
VpA
14
Vi
12
Sync
Load
13
11
-1
COM B
VpB

Fig. 4

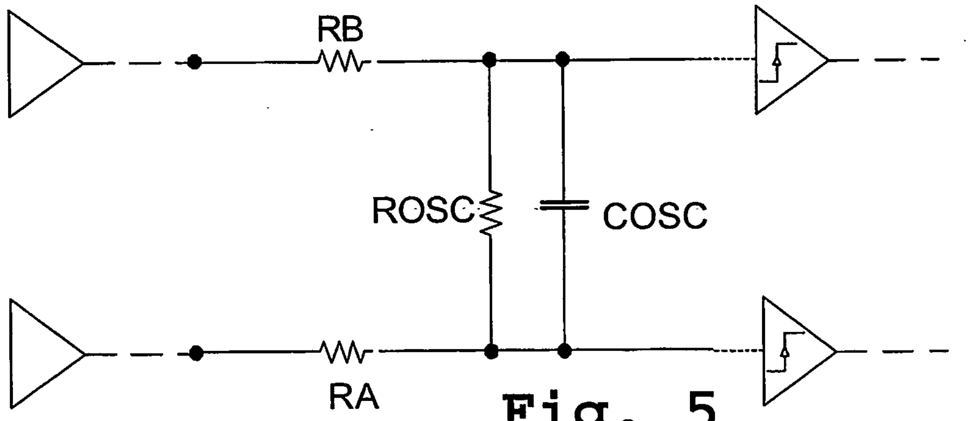

Fig. 5

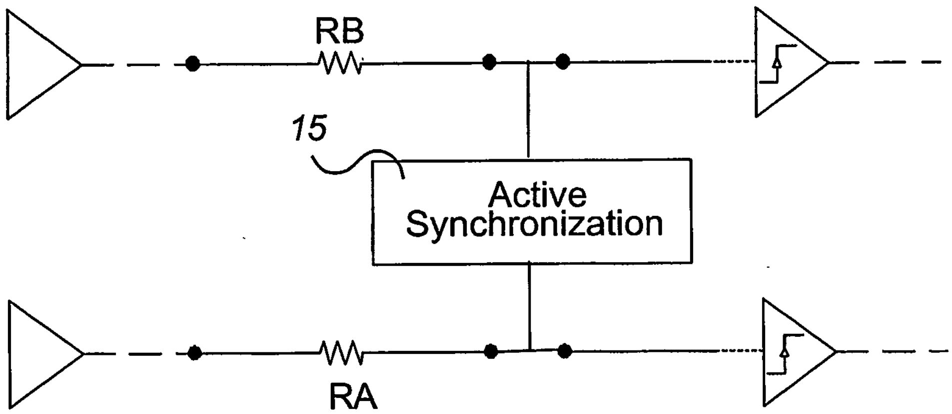

Fig. 6

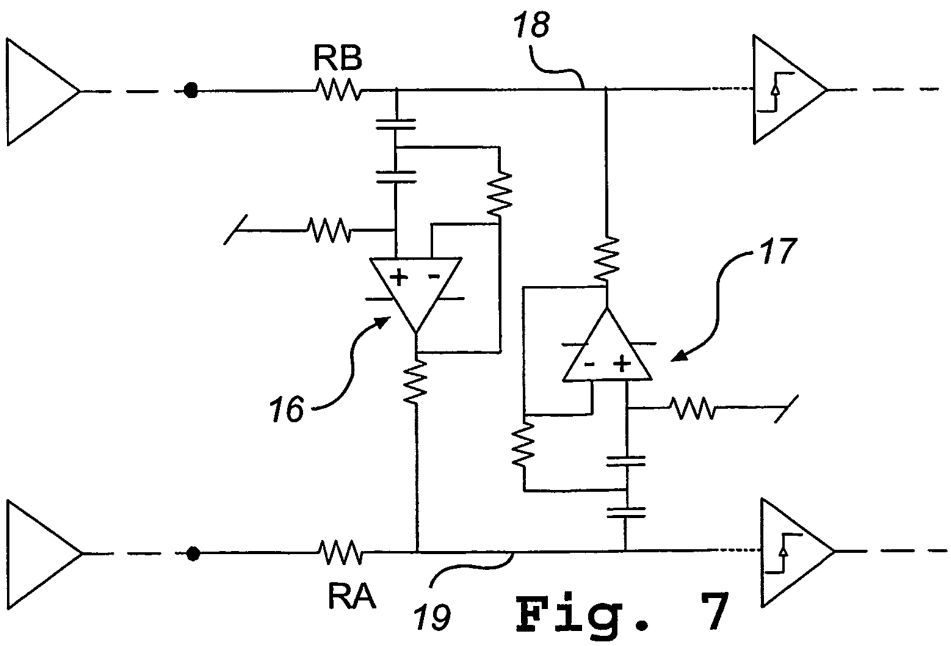

Fig. 7

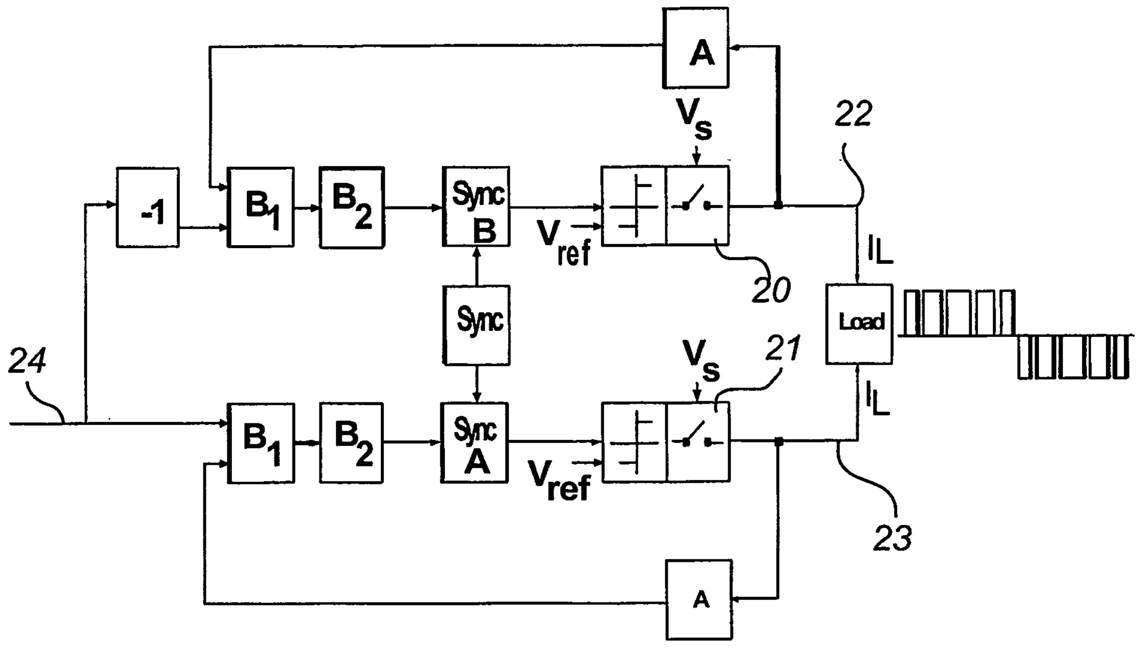
A
V_s
22
-1
B_1
B_2
Sync B
V_{ref}
I_L
20
Sync
Load
24
V_s
21
B_1
B_2
Sync A
V_{ref}
I_L
23
A

Fig. 8

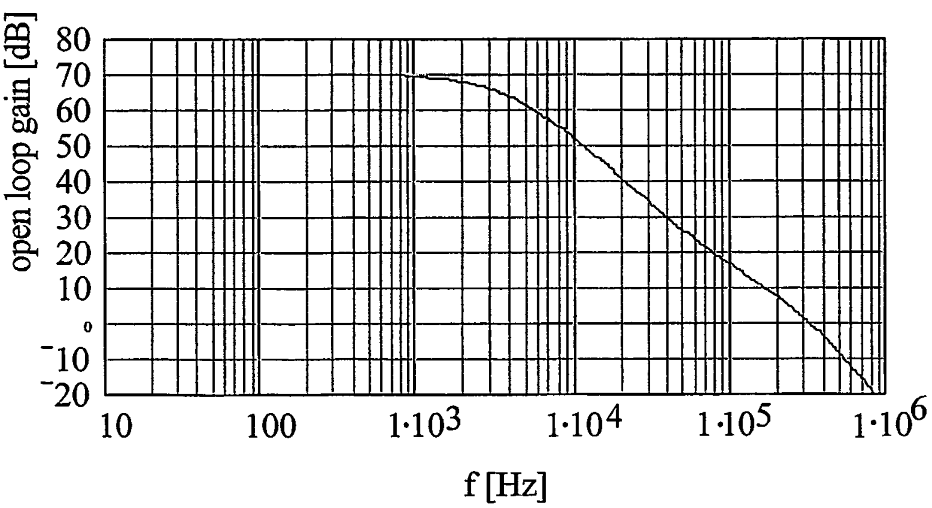
open loop gain [dB]
80
70
60
50
40
30
20
10
0
-10
-20
10
100
1·10³
1·10⁴
1·10⁵
1·10⁶
f [Hz]

Fig. 9

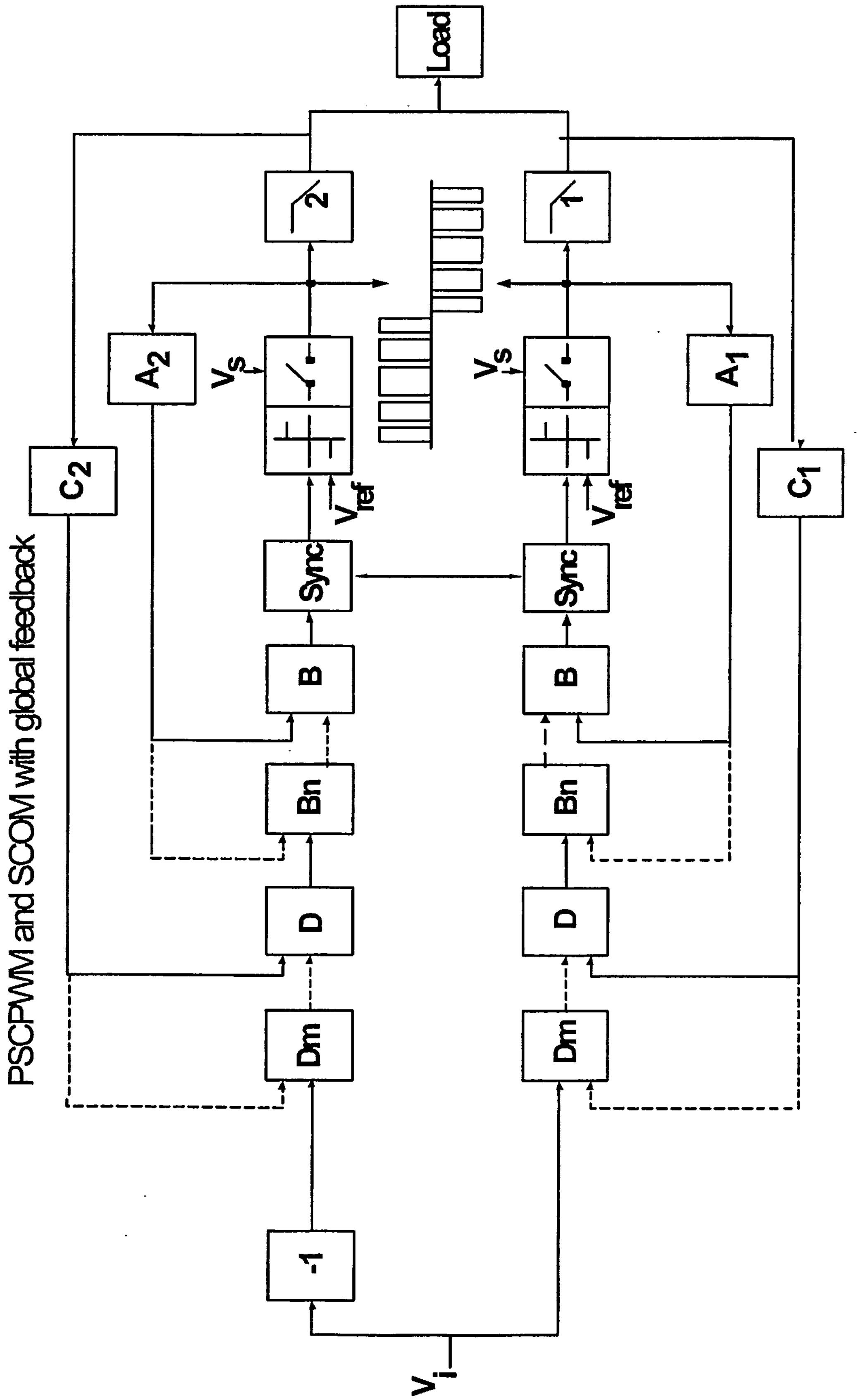
PSCPWM and SCOM with global feedback
Load
2
1
A2
A1
C2
C1
Vs
Vs
Vref
Vref
Sync
Sync
B
B
Bn
Bn
D
D
Dm
Dm
-1
Vi

Fig. 10

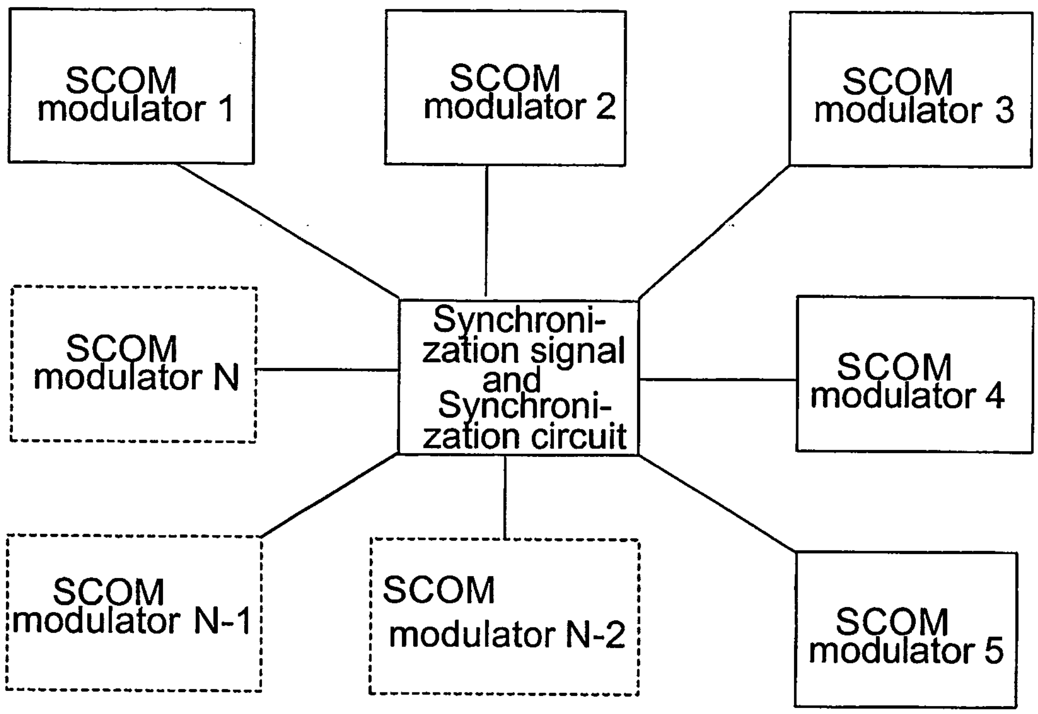
SCOM modulator 1
SCOM modulator 2
SCOM modulator 3
SCOM modulator N
Synchroni-zation signal and Synchroni-zation circuit
SCOM modulator 4
SCOM modulator N-1
SCOM modulator N-2
SCOM modulator 5

Fig. 11

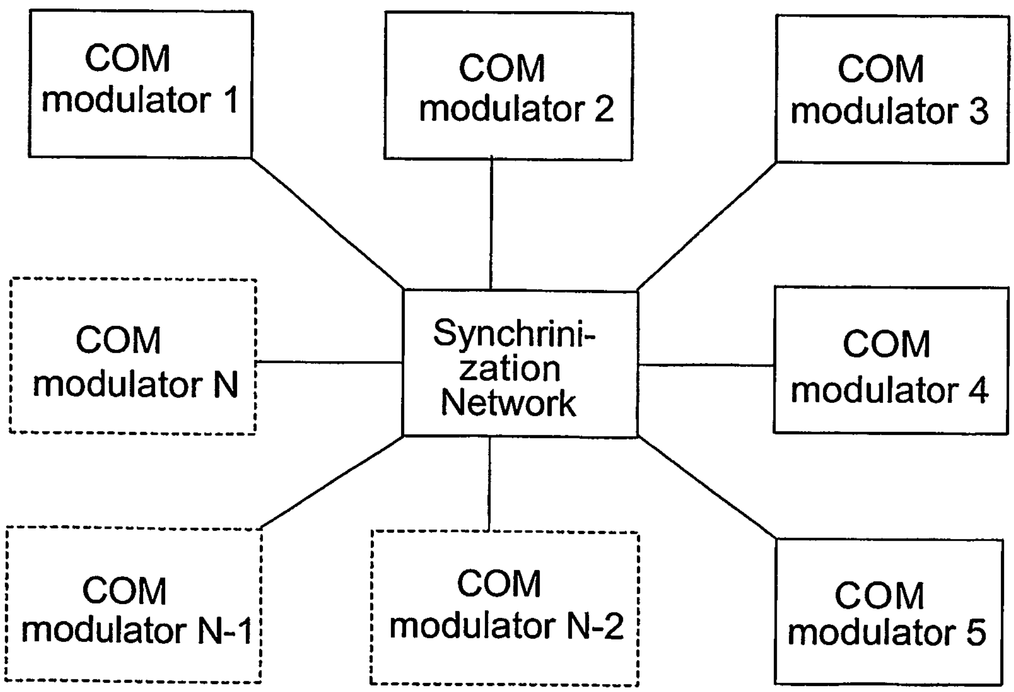
COM modulator 1
COM modulator 2
COM modulator 3
COM modulator N
Synchrini-zation Network
COM modulator 4
COM modulator N-1
COM modulator N-2
COM modulator 5

Fig. 12

REFERENCES CITED IN THE DESCRIPTION

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- SE 00033423 **[0021]**
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