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(54) **RAILWAY TRACK CIRCUIT MONITOR**

ÜBERWACHUNGSVORRICHTUNG FÜR GLEISSTROMKREISE

DISPOSITIF DE SURVEILLANCE POUR CIRCUITS DE VOIE FERRÉE

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WO-A2-2006/127066
DE-A1- 3 232 594

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Description

Technical Field

[0001] The present invention relates to railway track circuit monitors.

Background

[0002] It is known to monitor the absence of a train on a section of track using a track circuit, the track circuit comprising a relay. The relay comprises two inductive coils and a pivotable vane, arranged to be capable of pivoting in a magnetic field generated by coils of the relay. The pivoting motion of the vane is converted into linear movement by suitable linkages and the linkages arranged to operate switches. The flux-generating coils are referred to as the local coil and the control coil. The local coil is driven by a respective energising source, such as a fixed reference source derived from a signalling supply, whereas the control coil is driven by the track circuit which includes an energising source and a length of railway track. The presence of a train on the track section will influence the drive signal to the control coil, and will therefore influence operation of the relay, which in turn can be monitored at a base station. It is important to monitor that the relays are operating correctly.

[0003] In such monitoring of track circuits it was found that using the presently implemented method of simple current transducer measuring technology (applied to the relay end of the track circuit) would often return unexpected signals during the track shunted (occupied) state. Such unexpected signals were considered indicative of the onset of a possible fault condition, either of the track, the relay or the track circuit. Indeed in some cases the signal perturbations were so large as to indicate an apparent failure of the track circuit. However on physical inspection of the relay it was found that the relay operated normally and seemed immune to the signal perturbations.

[0004] A significant time-cost is involved in checking the relay in response to detection of the signal perturbations. We therefore seek to provide rail track relay monitoring.

[0005] Prior art documents EP 1746009 and WO 2006/127066 both disclose circuits for detecting the track circuit output signal by checking the phase between the track signal and a reference signal. They both use controllers, but they are both circuits which work alone. There is no monitoring of the function of an already existing vane track relay. So they cannot be used as monitoring of an existing and certified installation with vane track relays, but they would imply the replacement of these vane track relays with a completely new installation, which would imply a more exhaustive certification.

Summary

[0006] According to a first aspect of the invention there is provided a railway track circuit monitor for connection to a track circuit, the track circuit comprising a vane track relay, the monitor comprising a signal processor, the signal processor arranged to receive an input of a control relay drive signal and an input of a local relay drive signal, wherein the signal processor configured to provide an output signal determined by at least the relative phase between the control relay drive signal and the local relay drive signal, which output enables the monitoring of the operation of the track relay.

[0007] According to a second aspect of the invention there is provided a method of monitoring the operation of a railway vane track relay comprising connecting a railway track circuit monitor to a track circuit, which circuit comprises the vane track relay, and the monitor comprising a signal processor arranged to process a control relay drive signal and a local relay drive signal and generating an output signal which is determined by at least the relative phase between the drive signals, and the output signal enabling the operation of the relay to be monitored

Brief description of the drawings

[0008] Various embodiments of the invention will now be described, by way of example only, with reference to the following figures in which:

Figure 1 is a schematic view of a section of occupied rail track,

Figure 2 is an equivalent circuit of the rail track of Figure 1,

Figure 3 is a block diagram of part of a monitor of a rail track relay,

Figures 4 to **10** are traces of signals of the monitor of Figure 3,

Figure 11 is a block diagram of the monitor of Figure 3,

Figures 12, 12a and **12b** are plots of a processed and an unprocessed relay drive signal, and

Figures 13, 13a and **13b** are plots of a processed and an unprocessed relay drive signal.

Detailed description

[0009] Reference is made to Figure 1 which shows a section of rail track occupied by a wheelset 30, the railway track provided with a track circuit monitor 2 and a track circuit comprising a track relay 1. The railway track comprises a signalling rail 10, a common rail 11 and a conductor rail 13. The wheelset 30 is driven along the track by a motor 31 which receives a supply electrical energy from the traction rail 13, via a shoe 32. The relay 1 comprises a control coil, a local coil and a pivotable vane driven by the magnetic field generated by the (net) magnetic field generated by the coils.

[0010] A railway track circuit sharing a common return rail with the traction supply will always experience related interference. Even with the track shunted, considerable interference energy can find its way to the track relay 1. It will now be explained, in simplified terms, how traction interference can appear at the track relay 1.

[0011] The value of the train drop-shunt, R_{SHUNT} between AB has been considered to be close to zero, i.e. a perfect shunt.

[0012] For the purposes of this explanation the ballast losses have also been considered negligible.

[0013] For typical track circuits the length of rail BC (between the train shunt and the relay) presents an impedance, Z_{RAIL} comprising the following components:

- R_{DC}, the resistance at d.c. is typically very low in the order of tenths of milliohms
- X_L, the inductive reactance, which at 50Hz and above is not insignificant (typically of the order of hundreds of milliohms reactive)
- R_{AC}, the resistance at a.c. (skin effect) which again should not be considered as negligible (typically of the order of tens of milliohms)

[0014] For a short track circuit it is assumed that the rail impedance Z_{RAIL} between BC is constantly of the order of 1 milliohm from d.c. to a.c. This has been converted into an equivalent schematic shown in Figure 2. Suppose the traction current, $I_{TRACTION}$, is of the order of 500A and pulsing off every so often (perhaps due to poor shoe contact). This would present short 500A current pulses flowing through the rail BC, Z_{RAIL} of 1 milliohm causing 0.5V pulses to appear across the track relay 1.

[0015] The track relay 1 will typically pick with only about 1Vac 50Hz, so 0.5Vpk pulses of impulsive interference will add a significant contribution to the overall energisation to the control coil of the relay.

[0016] Also, the impedance presented by the control coil (for a capacitive fed application) is typically about 4 or 5 Ohms at 50Hz but drops off steeply either side of this to about 1 Ohm, so 0.5Vpk impulsive voltages applied to the coil can cause substantial peak currents to flow.

[0017] If the traction current was not interrupted, the dominant d.c. component would impress about 0.5Vdc continuously across the relay coil.

[0018] Furthermore this d.c. current would also contain ripple components of 300Hz (or 600Hz depending on the rectification method used at the sub-station) and probably a small amount of residual 50Hz.

[0019] It should also be noted that when the track section is clear, any interference signals (due to pulsating d.c. traction currents etc) will manifest themselves by effectively adding to the track feed supply and will appear in the relay end current.

[0020] Even if non-electric stock is running on electrified track, any pulsating d.c. traction currents flowing through the common rail can appear across the relay during shunted or unoccupied states.

[0021] However, despite the presence of the above sources of interference the operation the relay 1 is immune to the intrusion of such unwanted energisation.

[0022] This apparent immunity to interference lies in the fact that the moving part of the relay 1 (i.e. the vane) is actuated by interacting magnetic fields derived from two energising sources inducing currents (and hence magnetic fields) in the vane. The energising sources provide drive signals to energise the coils.

[0023] These sources are:

- A local supply (for example 110Vac at 50Hz) to energise the local coil.
- The electrical energy retrieved from the relay end of the track circuit to energise the control coil.

[0024] The two sources must be of the same frequency and a specified phase relationship in order to actuate the vane.

[0025] If the two coil energising sources differ in frequency by a "small" amount, there will be some motion of the vane. If for argument sake the two frequencies differed by 0.1Hz, the relay would open and close every 10s with a duty cycle close to 50%. If the frequency difference was 10Hz, for example the local supply was 50Hz and somehow there was 60Hz energy arriving at the control coil, the vane would attempt to open and close the contacts ten times a second. The rotational inertia of the vane and associated mechanics would prohibit this and the mechanism would just buzz, with the front contacts of the switches of the relay remaining open circuit.

[0026] In addition to the requirement of frequency identity, the phase relationship between the source currents must be such to generate the required rotational force (torque) on the vane. In practice the local and control currents need to be approximately in anti-phase (using the convention of the baseboard numbering for coil start and end assignments) in order to achieve full actuation of the vane and close the front contacts. If the currents are 90deg phase related there will always be zero net torque on the vane, and the front contacts remain open (relay dropped). A half way condition of a 45deg phase shift could cause partial actuation of the vane, but probably not enough to actually close the front contacts. If the currents are in-phase, the vane would be driven in the opposite direction attempting to open the front contacts even more.

[0027] In summary, the relay 1 rejects intrusive a.c. currents that are of different frequencies and/or incorrect phase. It should also be noted that the relay 1 is also immune to d.c. currents in the track circuit, this is an extension of the idea that the frequency difference would now be 50Hz to which the relay mechanism simply could not respond, it would just buzz.

[0028] The composition and functionality of the track circuit monitor 2 will now be described. Operation of the monitor 2 can be viewed into two processing stages, denoted as 2a and 2b, respectively. The first stage 2a includes the input of relay drive signals and that of (synchronous) rectification, whereas the second stage 2b includes post-rectification filtering and output. The currents flowing towards the relay coils, comprising respective relay drive signals, which signals provide a measure of current flowing in local and control coils, are sensed using current transformers CT1 and CT2. It will be appreciated that CT1 could be connected so as to either (i) monitor the current through the control coil or (ii) monitor the current flowing in the end of the track circuit conveyed to the relay 1. The currents are then converted into voltages and amplified using identical gain stages (to preserve phase matching) by amplifiers 20. A limiter 21 clips the local coil drive signal to convert it into a square wave, this provides the reference signal, REF, that drives two commutating electronic switches SW1 and SW2. SW1 turns ON when REF is positive whilst SW2 stays OFF. Correspondingly when REF goes negative the switch status is reversed i.e. SW2 turns ON, SW1 turns OFF.

[0029] The control coil drive signal after amplification at 20, is then duplicated to provide non-inverted and inverted versions of the signal, by way of amplifiers 22a and 22b.The non-inverted or inverted signal is then selected by electronic switches SW1 and SW2 according to the status of the reference signal REF as described above.

[0030] For the purpose of the explanation which follows, it is assumed that the relay 1 operates when the local and control drive signals are in phase (and of the same frequency). In fact, the drive signals have to be in anti-phase for actuation of the vane of the relay 1. However, that requirement is easily accounted for by turning either of the CTs through 180deg or reversing the output connections.

[0031] We now consider how the monitor 2, during the rectification of the first stage 2a, responds to different control coil drive signals. It is assumed that the peak magnitude of the control current is unity for purposes of simplicity.

[0032] In each of the examples described below, the local coil drive signal remains constant at 50Hz and effectively defines an absolute phase reference.

[0033] Reference is made to Figure 4, which shows a trace of signals present at the monitor 2. The output, SYNCH-OUT, from the first stage is a full wave rectified version of the control coil drive signal, and has a positive d.c. average value of 0.6366V (in fact $2/\pi$ x pk value). The relay 1 will operate because a net positive torque is developed in the vane. The positive d.c. value is the is the output which is ultimately produced by the monitor 2, at the second stage, which is described below.

[0034] Figure 5 shows a further trace in which the output from the synchronous rectifier is a full wave rectified version of the control drive signal and has a negative d.c. average value of -0.6366V (in fact $-2/\pi$ x pk value). The relay 1 will not operate because a net negative torque is developed in the vane. Under "normal circumstances" one would expect the monitor 2 to filter out the a.c. component (as before) and produce a pure negative d.c. output. However in the present embodiment, this negative signal is used to assert an alarm output, warning that the relay is being energised by a non-legitimate source, see later.

[0035] Figure 6 shows a trace in which the average d.c. value of SYNCH-OUT is zero. The synchronous rectifier has rejected a control current in positive quadrature. The relay 1 behaves in the same manner because there is a net zero torque on the vane. The monitor 2 will output, at the second stage, a zero d.c. value, the a.c. component is removed by filtering.

[0036] Figure 7 shows a trace in which the average d.c. value of SYNCH-OUT is zero. The synchronous rectifier has rejected a control current in negative quadrature. The relay behaves in the same manner, because there is a zero net torque on the vane. This zero d.c. value is the signal that will be output from the monitor module, the a.c. component is removed by filtering during the second stage.

[0037] Figure 8 shows a further trace in which the average d.c. value of SYNCH-OUT is zero. Again, the relay vane will not turn because there is net zero torque. The a.c. component is filtered out during the second processing stage leaving just a zero output.

[0038] Figure 9 shows a trace in which the average d.c. value of SYNCH-OUT is zero. Again the twin vane VT1 relay vane will not turn because there is net zero torque. Ultimately, the monitor 2 filters out the a.c. component leaving just a zero output.

[0039] Figure 10 shows a further trace in which the d.c. value of SYNCH-OUT averaged over the 40ms duration shown is -0.125 which is 12.5% of the d.c. step. If the signal is averaged over longer than 40ms, which is likely in practice, by virtue of low-pass filtering (described below in relation to the second processing stage) this value will rapidly decay to zero. In fact it reaches a negative 1% of the step value after 0.5s. If the step had occurred at t= 5ms the averaged value after 500ms would have outputted at approximately as a positive value 1% of step. After 40ms, SYNCH-OUT will be a $\pm$ 1 square wave which will always average to zero. The vane of the relay 1 will not turn because although the vane will be kicked by a short pulse, it cannot rotate instantly and after half a second, the vane will have settled to its true rest position in other words there is a net zero torque. During the second processing stage, the a.c. component, which will be pulse followed by a 50Hz square wave will be filtered out leaving just a zero output.

[0040] The second processing stage 2b will now be described, with reference to Figure 11.

[0041] The output, SYNCH-OUT, from the first processing stage described above, contains both d.c. and a.c. components. The d.c. component represents the synchronous value of the control drive signal, the a.c. component contains no useful value(s). Consequently the a.c. component is filtered out by a two-pole low-pass filter 25 rolling off at 2.4Hz emulating the mechanical inertia of the vane of the relay 1. The filtered d.c. value is input to a transmitter 26 in which it is converted to a 4-20mA industry standard output. Signals from the transmitter can then be transmitted to a (remote) base station so that the operation of the relay can be logged and/or monitored.

[0042] An alarm output is produced (and transmitted to the base station) if:

- The CTs are incorrectly phased, or
- The control coil relay circuit is "invaded" by 50Hz a.c. of incorrect phase.

[0043] The latter condition could occur if an isolated rail joint (IRJ) shorted out, importing track circuit energy from the adjacent track section which is energised in anti-phase, or of opposite polarity for d.c. track circuits.

[0044] Reference is now made to Figures 12, 12a and 12b which shows two plots, plot 40 and plot 41. The plot 40 shows a sensed control drive signal which has not been processed by the monitor 2, whereas the plot 41 shows the output from the monitor 2 resulting from the control signal having been processed by the monitor 2. The plot 40 includes what appears to be a series of current spikes that could be interpreted as poor drop-shunt performance. In contrast, the plot 41 illustrates that the monitor 2 has rejected this perturbation, probably caused by a "blast" of d.c. transients (e.g. a quick succession of d.c. high, low, high etc. currents) caused by intermittent traction supply issues, a d.c. step or perhaps a burst of inverter interference. Advantageously, the plot 41 has a much cleaner profile and is free from noise/interference spikes present in the plot 40. The drop in amplitude of the current is indicative of the presence of wheelset on the respective rail section. It is also to be noted that the track clear current before strike-in and after strike-out has not changed as much as monitored using the synchronous rectification of the monitor 2.

[0045] Reference is now made to Figures 13, 13a and 13b, which show plots 50 and 51 of sensed control drive signals. By way of explanation, Figure 13a and 13b show the individual plots, whereas Figure 13 shows the plots superimposed. Plot 50 is the sensed control drive signal without use of the monitor 2, whereas the plot 51 is the sensed control drive signal with use of the monitor 2. As can be seen, the unwanted interference spikes 55 are not present in the plot 51 (since they have been filtered out by the monitor 2). However, the discontinuities shown at 56 are representative of genuine track-shunt problems. Advantageously, and as shown at 56b in Figure 13b, the monitor 2 allows the discontinuities to pass, and so action can be taken to investigate the detected fault.

[0046] It will be appreciated that although the monitor 2 is shown as being implemented in the analogue domain, at least part of the functionality of the monitor 2 may be implemented in the digital domain (for example by way of a suitably configured digital data processor).

[0047] It will also be appreciated that although the above examples refer to d.c. railways, implementations of the invention are also applicable to a.c. electrified railways.

Claims

1. A railway track circuit monitor (2) for connection to a track circuit, the track circuit comprising a vane track relay (1), the monitor comprising a signal processor, the signal processor arranged to receive an input of a control relay drive signal and an input of a local relay drive signal, wherein the signal processor configured to provide an output signal determined by at least the relative phase between the control relay drive signal and the local relay drive signal, which output enables the monitoring of the operation of the track relay.

2. A monitor as claimed in claim 1 in which the signal processor comprises a synchronous rectifier.

3. A monitor as claimed in claim 1 or claim 2 in which the signal processor arranged to rectify the control relay drive signal.

4. A monitor as claimed in claim 3 in which the signal processor arranged to rectify the control relay drive signal in relation to the local relay drive signal.

5. A monitor as claimed in claim 4 in which the signal processor arranged to use the control relay drive signal as a time reference.

6. A monitor as claimed in any preceding claim in which the signal processor arranged such that when a predetermined phase relationship exists between the control relay drive signal and the local relay drive signal the output signal has a predetermined characteristic indicative of that relationship.

7. A monitor as claimed in claim 6 in which the characteristic indicative of the control relay drive signal and the local relay drive signal being substantially in phase or substantially in anti-phase.

8. A monitor as claimed in any preceding claim in which the value of the output signal is related to the relative

phase between the control relay drive signal and the local relay drive signal.

9. A monitor as claimed in any preceding claim in which the signal processor arranged to determine an alarm condition when a particular phase relationship is determined between the control relay drive signal and the local relay drive signal.

10. A method of monitoring the operation of a railway vane track relay (1) comprising connecting a railway track circuit monitor (2) to a track circuit, which circuit comprises the vane track relay, and the monitor comprising a signal processor arranged to process a control relay drive signal and a local relay drive signal and generating an output signal which is determined by at least the relative phase between the drive signals, and the output signal enabling the operation of the relay to be monitored

11. A method as claimed in claim 10 in which the output signal is also determined by the amplitude of the control drive signal.

Patentansprüche

1. Eisenbahn-Gleisstromkreis-Überwachungsgerät (2) zur Verbindung mit einem Gleisstromkreis, wobei der Gleisstromkreis ein Gleis-Anker-Relais (1) aufweist, wobei das Überwachungsgerät einen Signalprozessor aufweist, wobei der Signalprozessor dazu eingerichtet ist, einen Eingang eines Steuerrelais-Treibersignals und einen Eingang eines lokalen Relais-Treibersignals zu empfangen, wobei der Signalprozessor dazu ausgelegt ist, ein Ausgabesignal zu liefern, das mindestens durch die relative Phase zwischen dem Steuerrelais-Treibersignal und dem lokalen Relais-Treibersignal bestimmt ist, wobei die Ausgabe die Überwachung des Betriebs des Gleisrelais aktiviert.

2. Überwachungsgerät nach Anspruch 1, bei dem der Signalprozessor einen Synchrongleichrichter aufweist.

3. Überwachungsgerät nach Anspruch 1 oder Anspruch 2, bei dem der Signalprozessor dazu eingerichtet ist, das Steuerrelais-Treibersignal gleichzurichten.

4. Überwachungsgerät nach Anspruch 3, bei dem der Signalprozessor dazu eingerichtet ist, das Steuerrelais-Treibersignal in Bezug auf das lokale Relais-Treibersignal gleichzurichten.

5. Überwachungsgerät nach Anspruch 4, bei dem der Signalprozessor dazu eingerichtet ist, das Steuerrelais-Treibersignal als Zeitreferenz zu verwenden.

6. Überwachungsgerät nach einem der vorhergehenden Ansprüche, bei dem der Signalprozessor derart eingerichtet ist, dass, wenn eine vorbestimmte Phasenbeziehung zwischen dem Steuerrelais-Treibersignal und dem lokalen Relais-Treibersignal besteht, das Ausgabesignal eine vorbestimmte Charakteristik aufweist, die diese Beziehung anzeigt.

7. Überwachungsgerät nach Anspruch 6, bei dem die Charakteristik, die das Steuerrelais-Treibersignal und das lokale Relais-Treibersignal anzeigt, im Wesentlichen in Phase oder im Wesentlichen gegenphasig ist.

8. Überwachungsgerät nach einem der vorhergehenden Ansprüche, bei dem der Wert des Ausgabesignals auf die relative Phase zwischen dem Steuerrelais-Treibersignal und dem lokalen Relais-Treibersignal bezogen ist.

9. Überwachungsgerät nach einem der vorhergehenden Ansprüche, bei dem der Signalprozessor dazu eingerichtet ist, eine Alarmbedingung zu bestimmen, wenn eine bestimmte Phasenbeziehung zwischen dem Steuerrelais-Treibersignal und dem lokalen Relais-Treibersignal bestimmt wird.

10. Verfahren zum Überwachen des Betriebs eines Eisenbahngleis-Anker-Relais (1), aufweisend das Verbinden eines Eisenbahn-Gleisstromkreis-Überwachungsgeräts (2) mit einem Gleisstromkreis, wobei der Stromkreis das Gleis-Anker-Relais aufweist, und das Überwachungsgerät einen Signalprozessor aufweist, der dazu eingerichtet ist, ein Steuerrelais-Treibersignal und ein lokales Relais-Treibersignal zu verarbeiten und ein Ausgabesignal zu erzeugen, das durch mindestens die relative Phase zwischen den Treibersignalen bestimmt ist, und wobei das Ausgabesignal den Betrieb des zu überwachenden Relais aktiviert.

11. Verfahren nach Anspruch 10, bei dem das Ausgabesignal auch durch die Amplitude des Steuerungs-Treibersignals bestimmt wird.

Revendications

1. Dispositif de surveillance de circuit de voie ferrée (2) pour une connexion à un circuit de voie, le circuit de voie comprenant un relais de voie à aube (1), le dispositif de surveillance comprenant un processeur de signaux, le processeur de signaux étant agencé pour recevoir une entrée d'un signal d'attaque de relais de commande et une entrée d'un signal d'attaque de relais local, dans lequel le processeur de signaux est configuré pour fournir un signal de sortie déterminé par au moins la phase relative entre le signal d'attaque de relais de commande et le signal d'attaque de relais local, laquelle sortie permet la surveillance du fonctionnement du relais de voie.

2. Dispositif de surveillance selon la revendication 1, dans lequel le processeur de signaux comprend un redresseur synchrone.

3. Dispositif de surveillance selon la revendication 1 ou la revendication 2, dans lequel le processeur de signaux est agencé pour redresser le signal d'attaque de relais de commande.

4. Dispositif de surveillance selon la revendication 3, dans lequel le processeur de signaux est agencé pour redresser le signal d'attaque de relais de commande par rapport au signal d'attaque de relais local.

5. Dispositif de surveillance selon la revendication 4, dans lequel le processeur de signaux est agencé pour utiliser le signal d'attaque de relais de commande en tant que référence de temps.

6. Dispositif de surveillance selon l'une quelconque des revendications précédentes, dans lequel le processeur de signaux est agencé de sorte que, lorsqu'une relation de phase prédéterminée existe entre le signal d'attaque de relais de commande et le signal d'attaque de relais local, le signal de sortie ait une caractéristique prédéterminée indicative de cette relation.

7. Dispositif de surveillance selon la revendication 6, dans lequel la caractéristique indicative du signal d'attaque de relais de commande et du signal d'attaque de relais local est d'être sensiblement en phase ou sensiblement en antiphase.

8. Dispositif de surveillance selon l'une quelconque des revendications précédentes, dans lequel la valeur du signal de sortie est liée à la phase relative entre le signal d'attaque de relais de commande et le signal d'attaque de relais local.

9. Dispositif de surveillance selon l'une quelconque des revendications précédentes, dans lequel le processeur de signal est agencé pour déterminer une condition d'alarme lorsqu'une relation de phase particulière est déterminée entre le signal d'attaque de relais de commande et le signal d'attaque de relais local.

10. Procédé de surveillance du fonctionnement d'un relais de voie à aube ferrée (1) comprenant le fait de connecter un dispositif de surveillance de circuit de voie ferrée (2) à un circuit de voie, lequel circuit comprend le relais de voie à aube, et le dispositif de surveillance comprenant un processeur de signaux agencé pour traiter un signal d'attaque de relais de commande et un signal d'attaque de relais local et la génération d'un signal de sortie qui est déterminé par au moins la phase relative entre les signaux d'attaque, et le signal de sortie permettant de surveiller le fonctionnement du relais.

11. Procédé selon la revendication 10, dans lequel le signal de sortie est également déterminé par l'amplitude du signal d'attaque de commande.

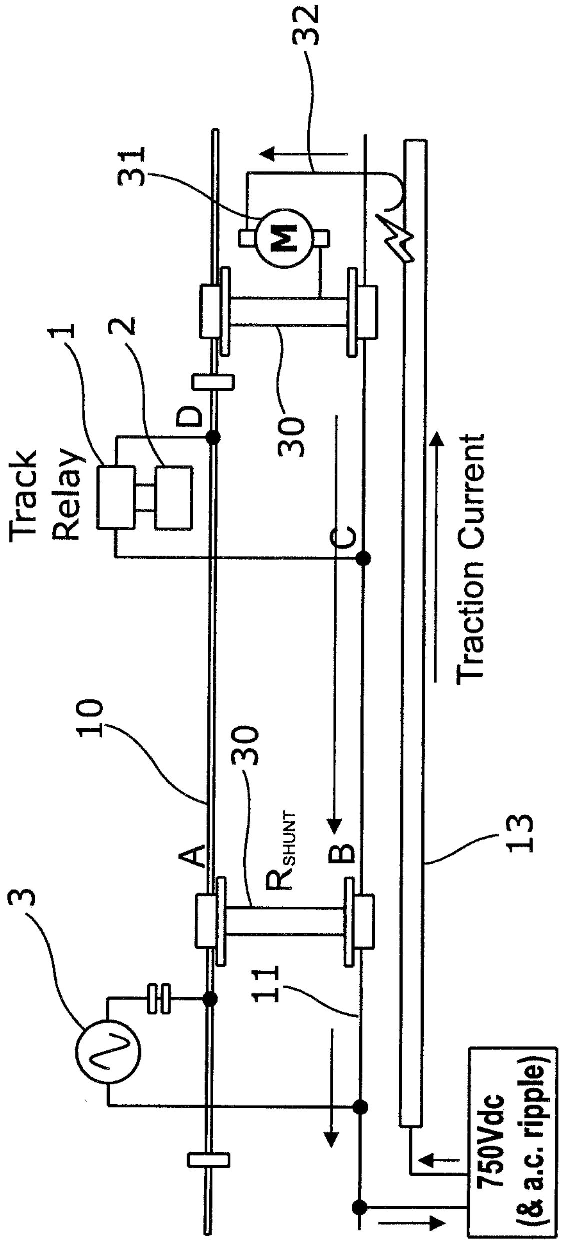
Track
Relay
1
2
D
C
3
A
R_{SHUNT}
B
10
30
11
30
31
32
M
13
Traction Current
750Vdc
(& a.c. ripple)

Fig. 1

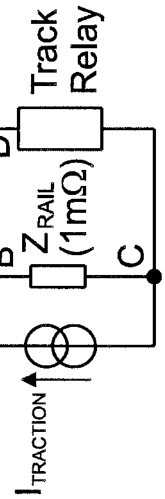
$I_{TRACTION}$
B
Z_{RAIL}
(1mΩ)
C
D
Track
Relay

Fig. 2

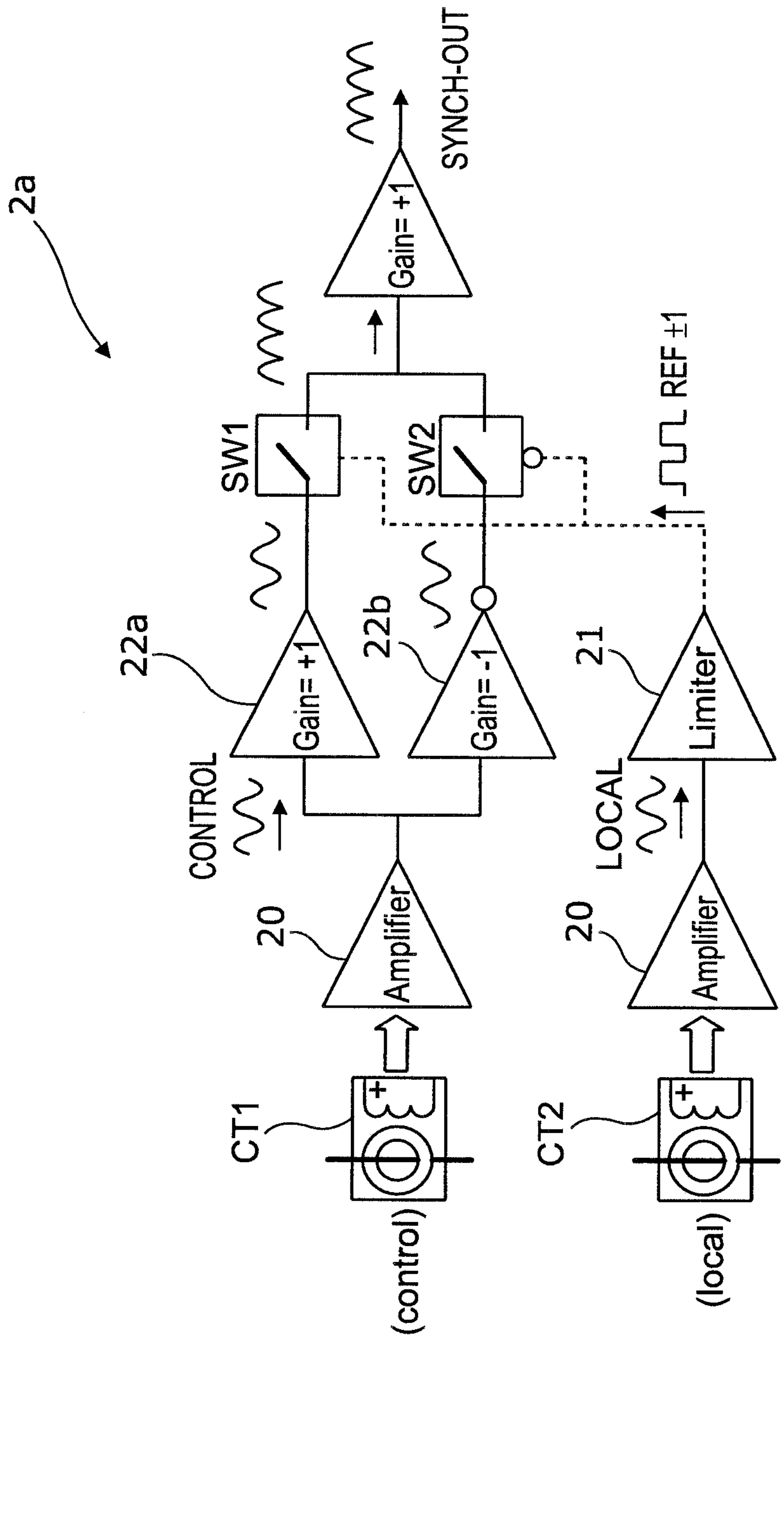
2a
SYNCH-OUT
Gain= +1
SW1
SW2
REF ±1
22a
Gain= +1
22b
Gain= -1
CONTROL
LOCAL
21
Limiter
20
Amplifier
20
Amplifier
CT1
CT2
(control)
(local)

Fig. 3

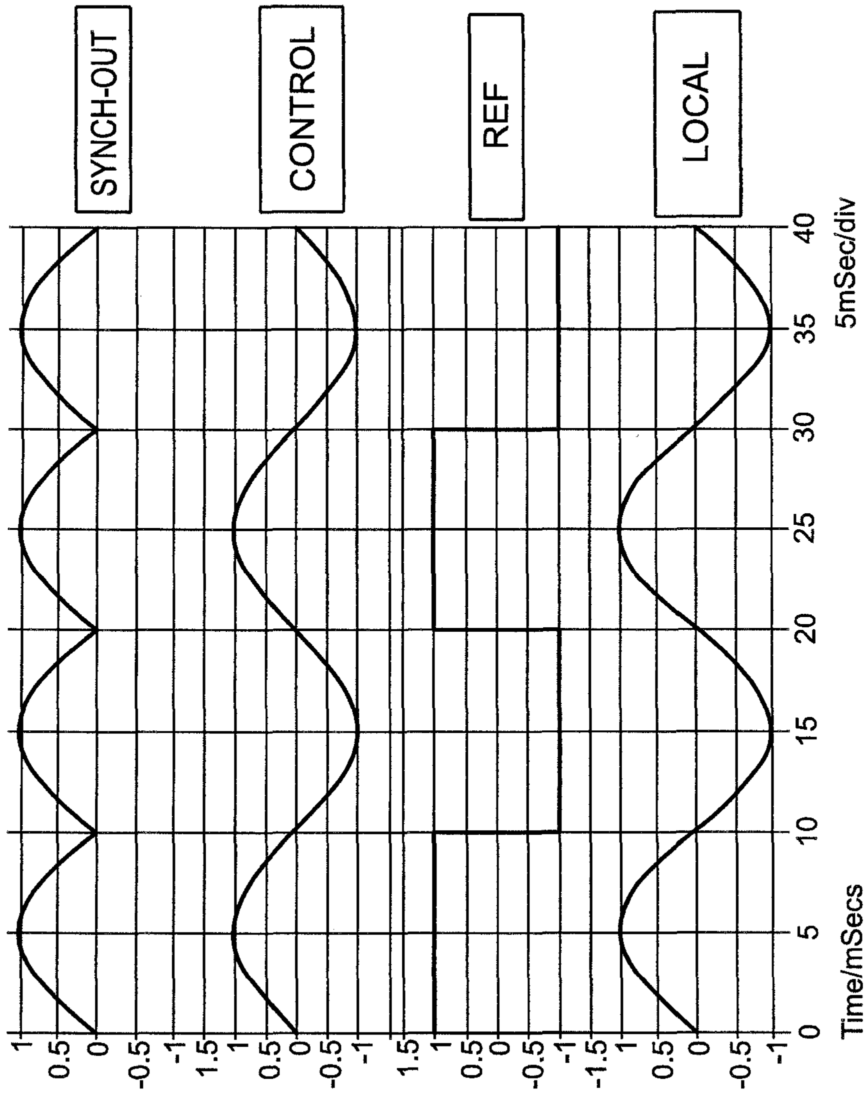
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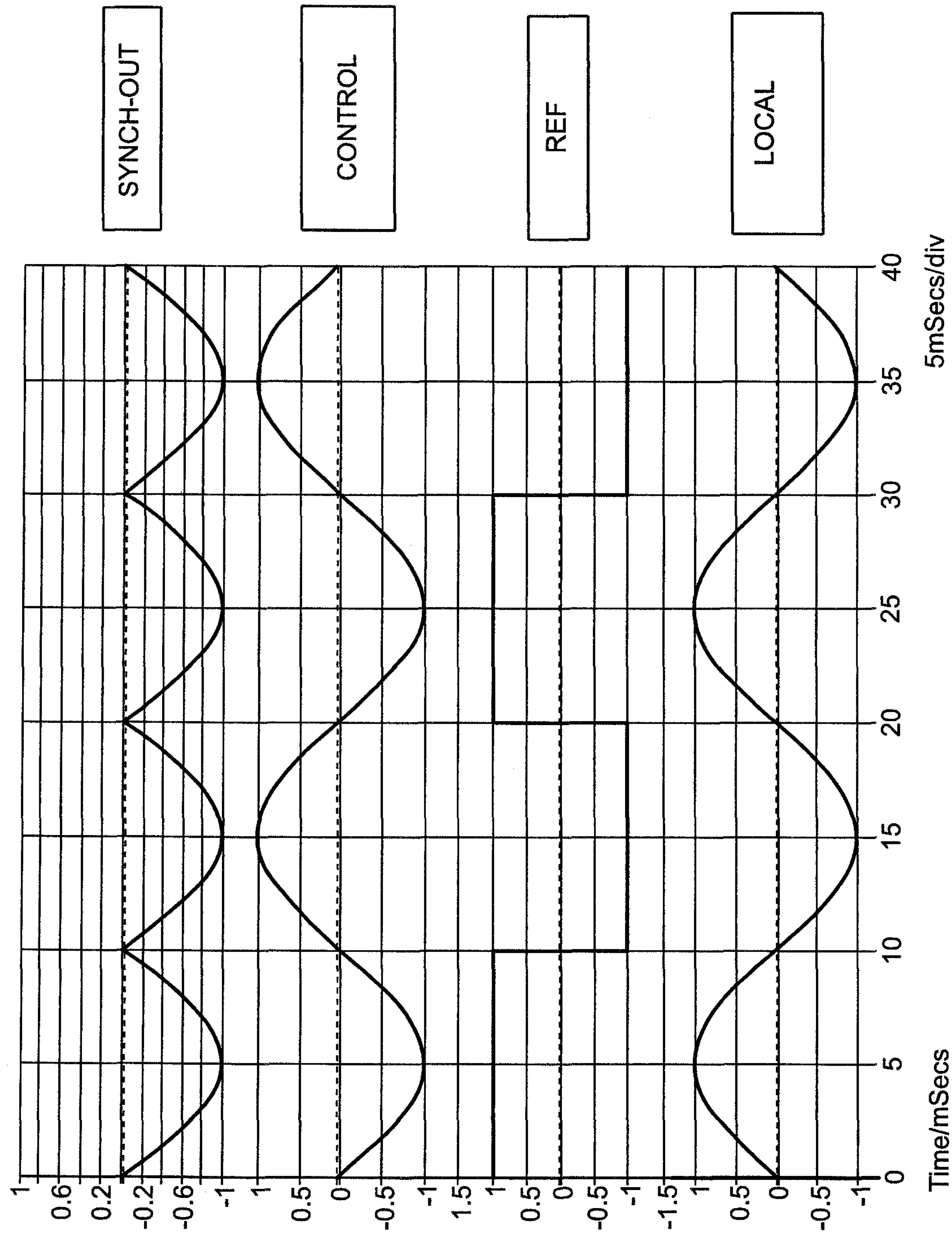
Fig. 4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0
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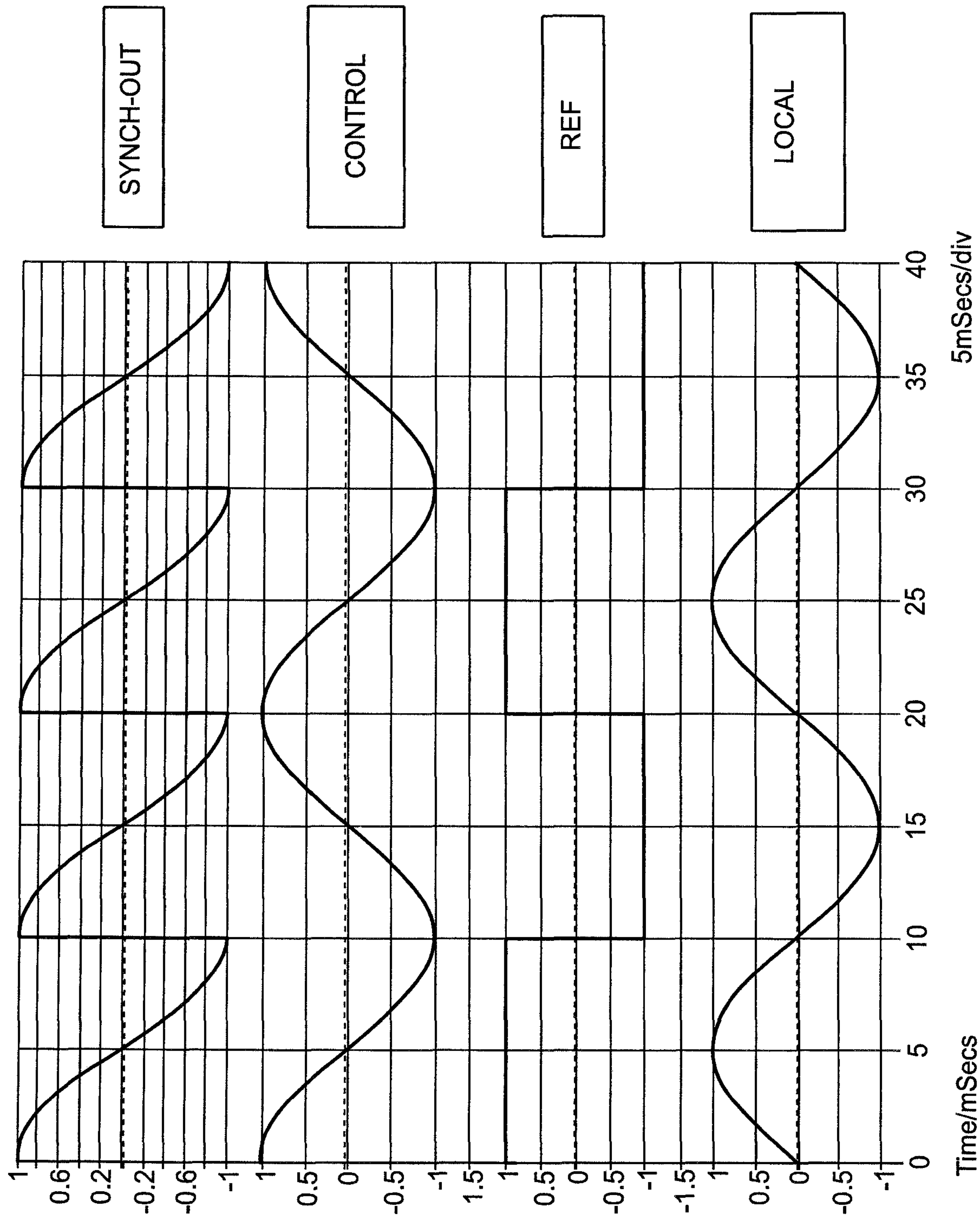
-1.5

Fig. 5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0
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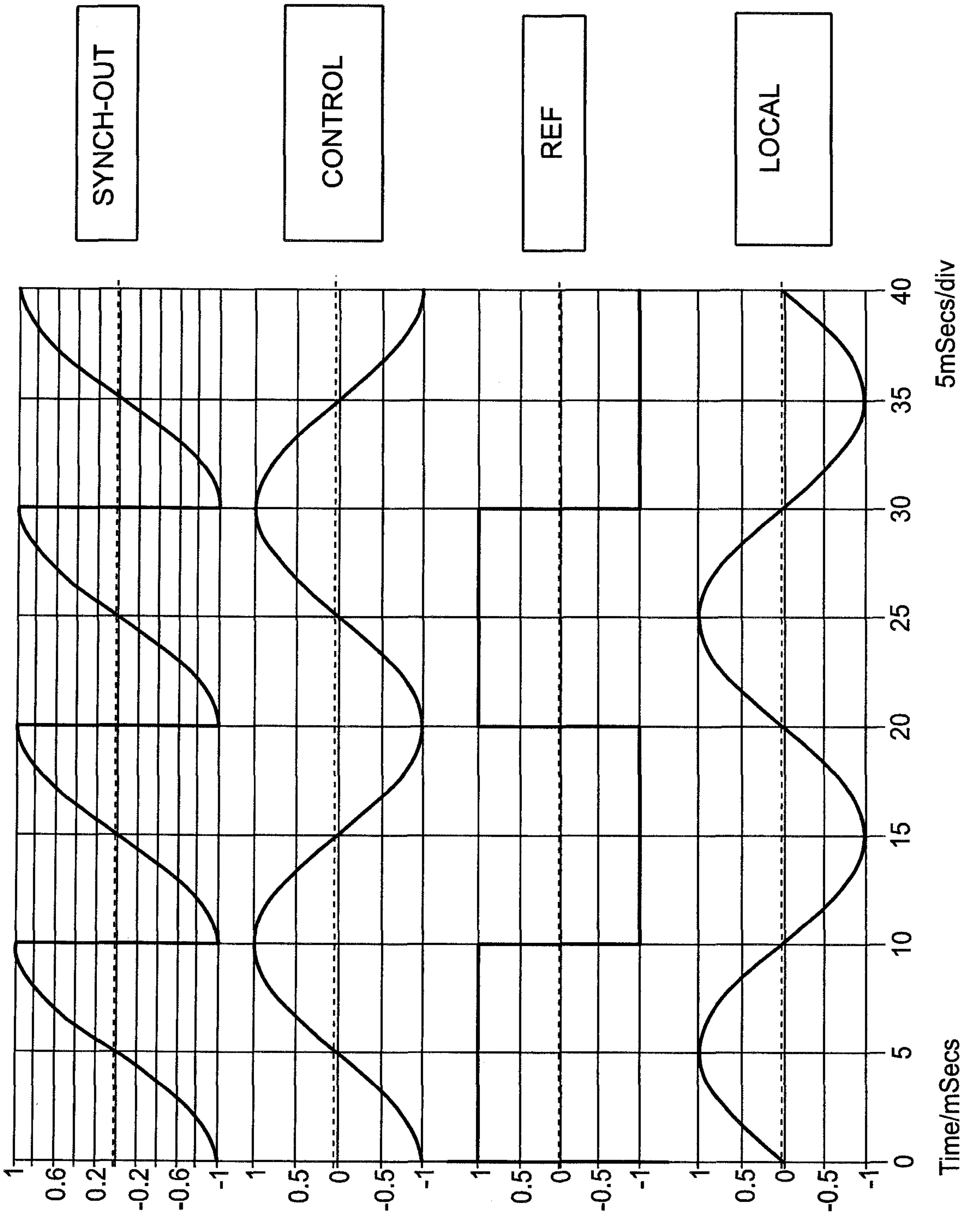
Fig. 6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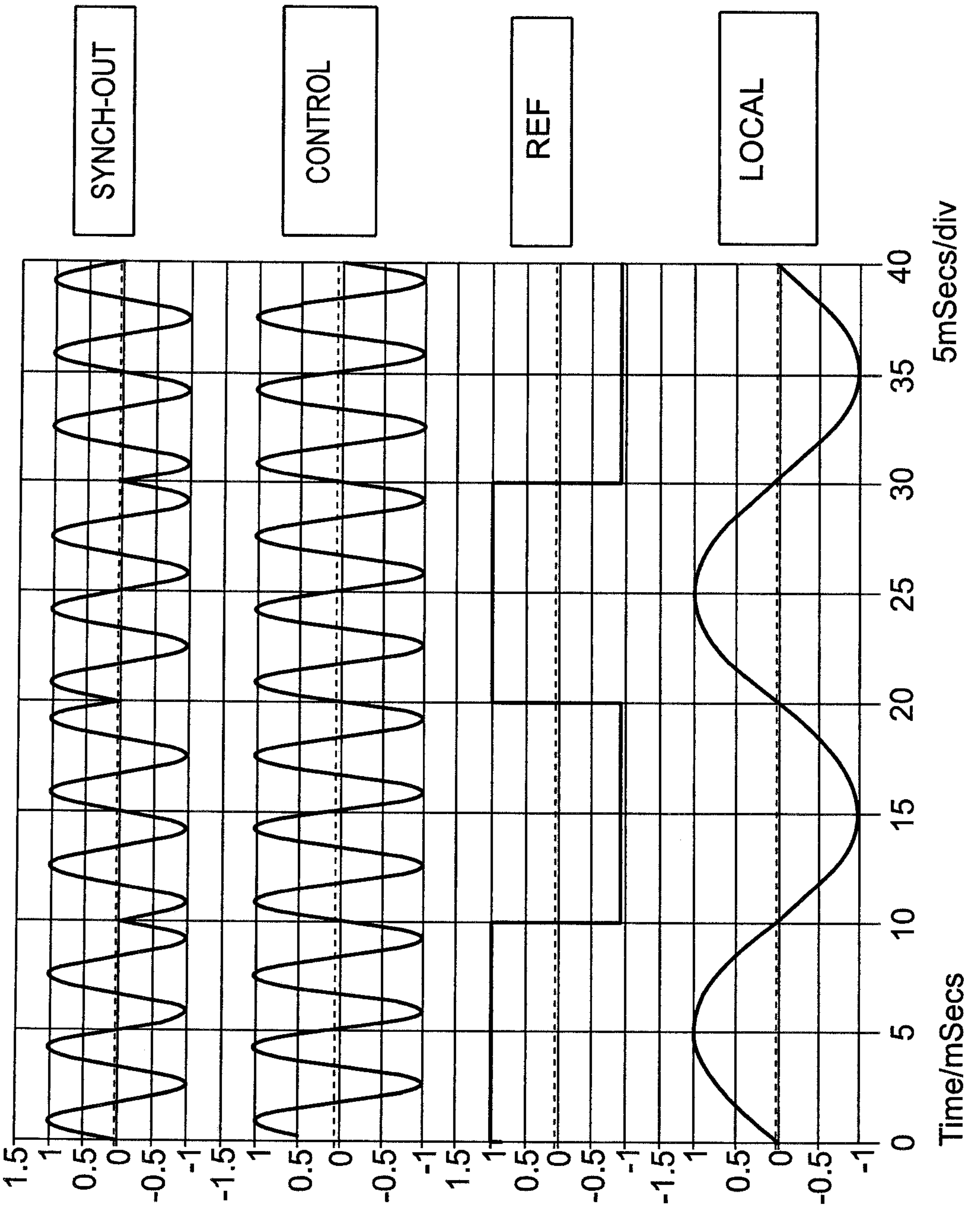
-0.5

Fig. 7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-1
-1.5

Fig. 8

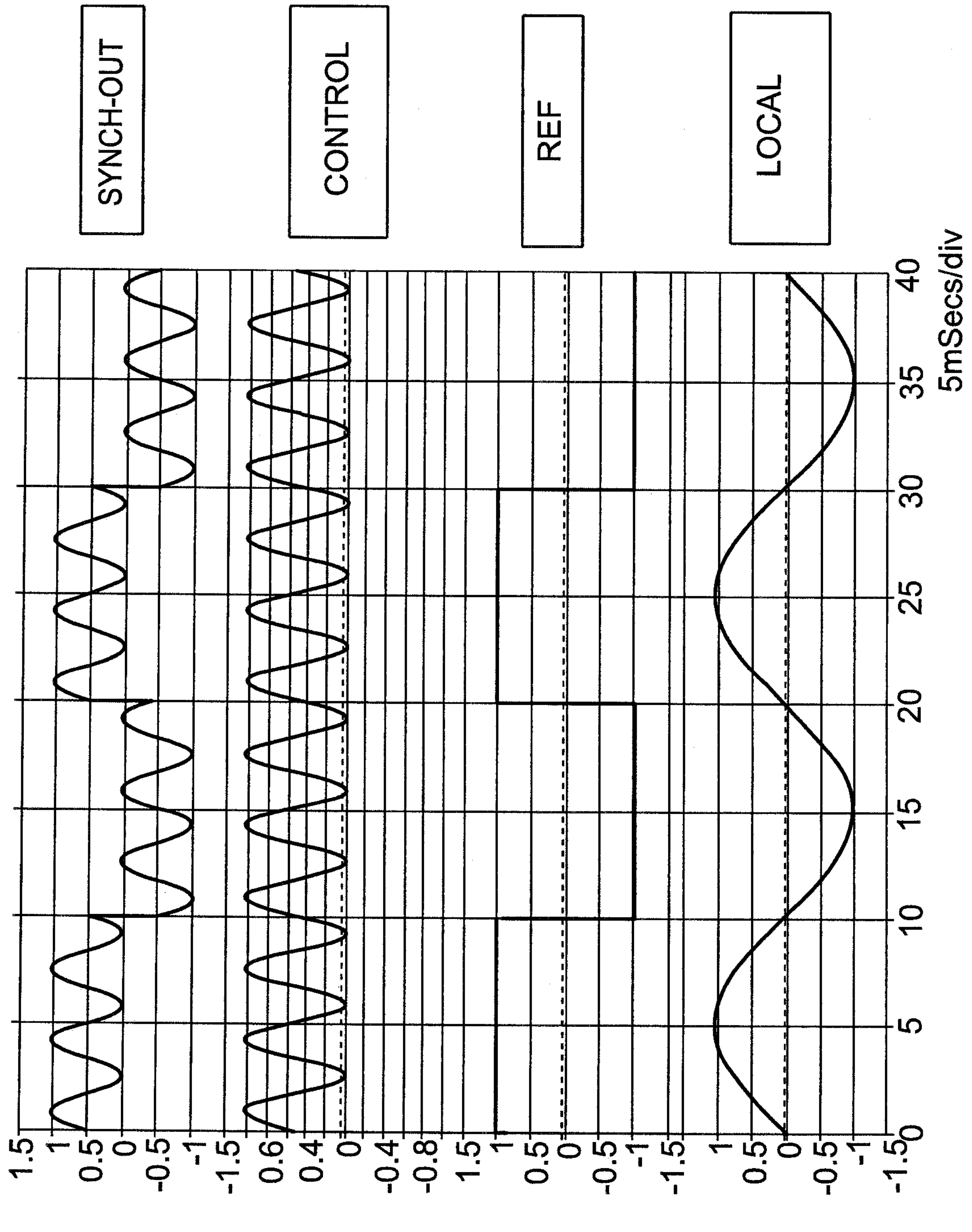


Fig. 9

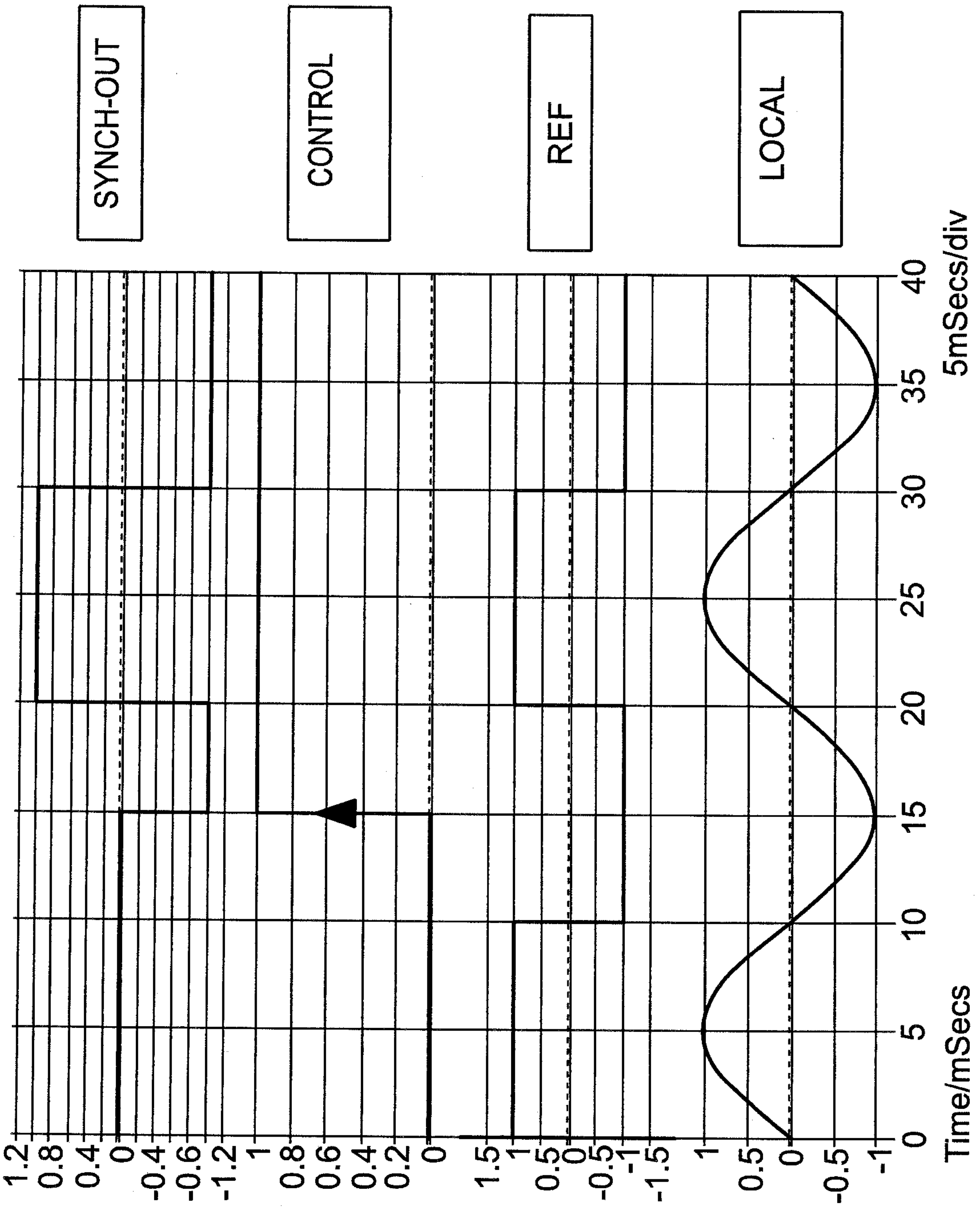


Fig. 10

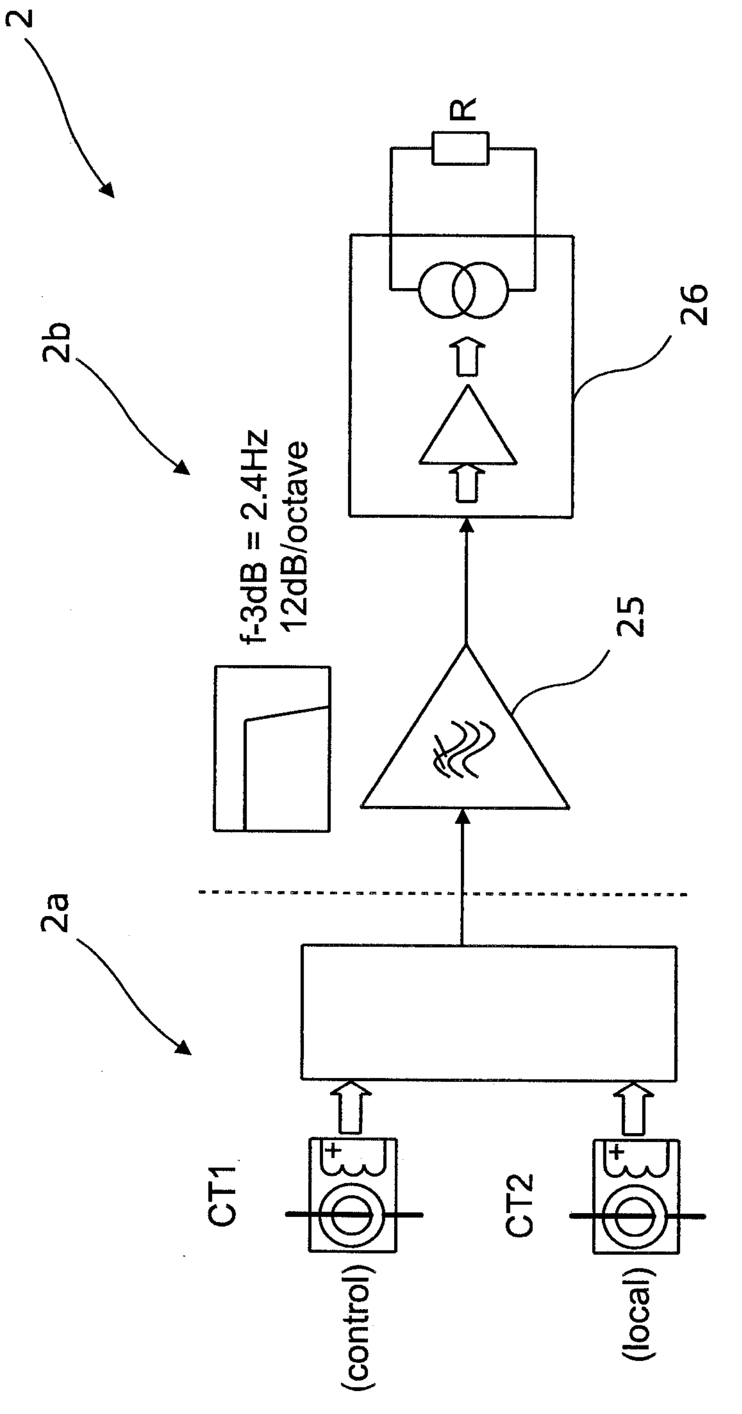


Fig. 11

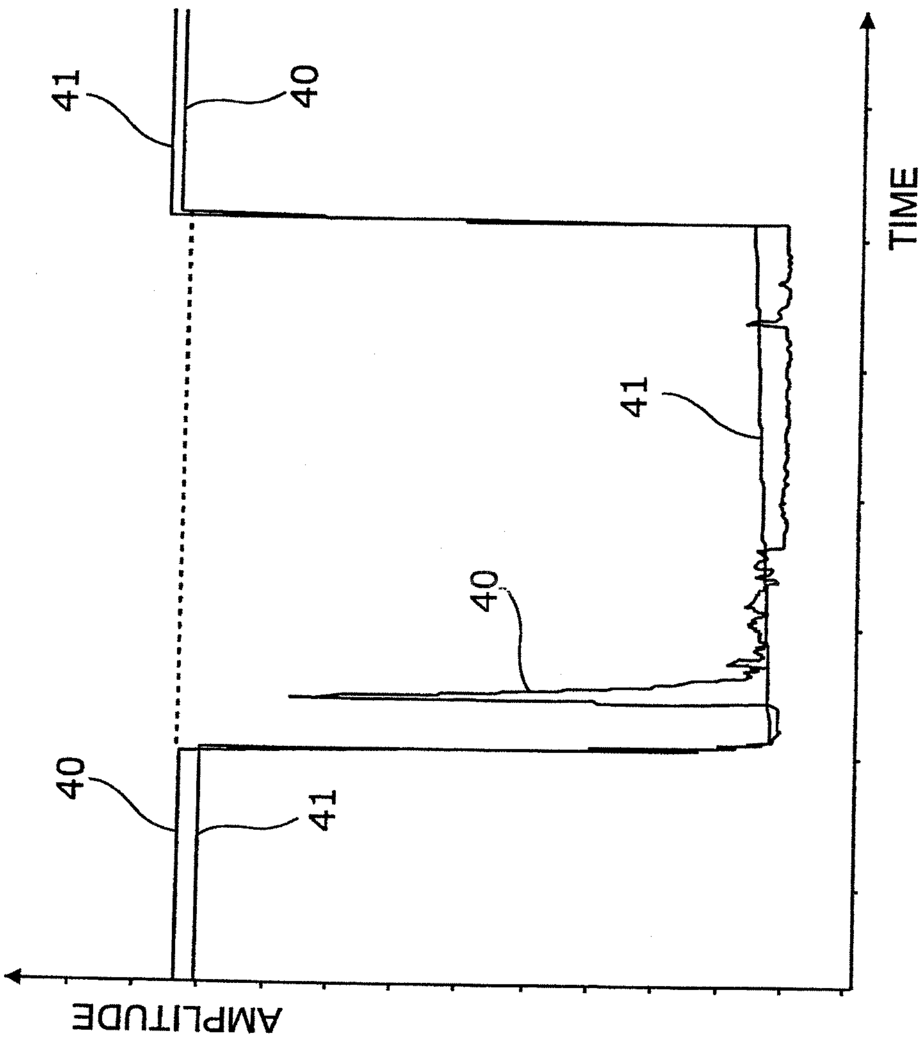


Fig. 12

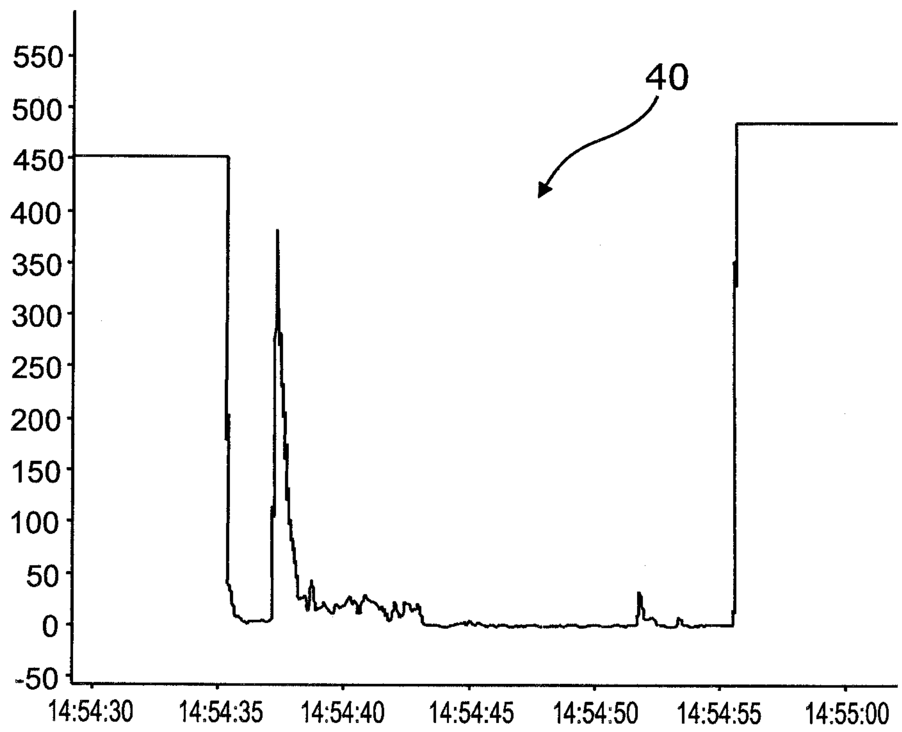


Fig. 12a

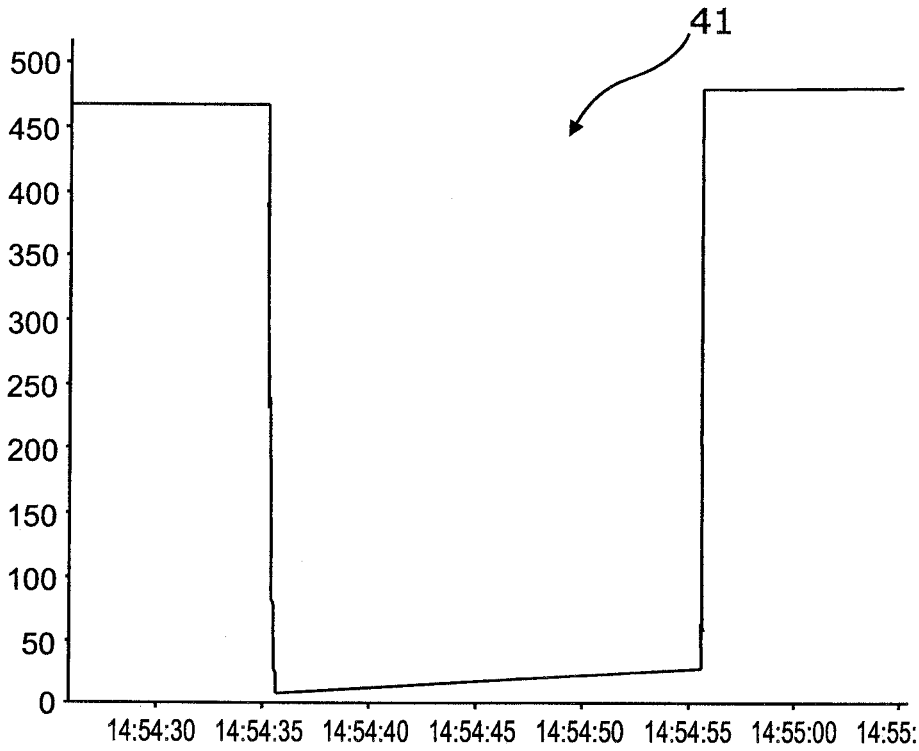
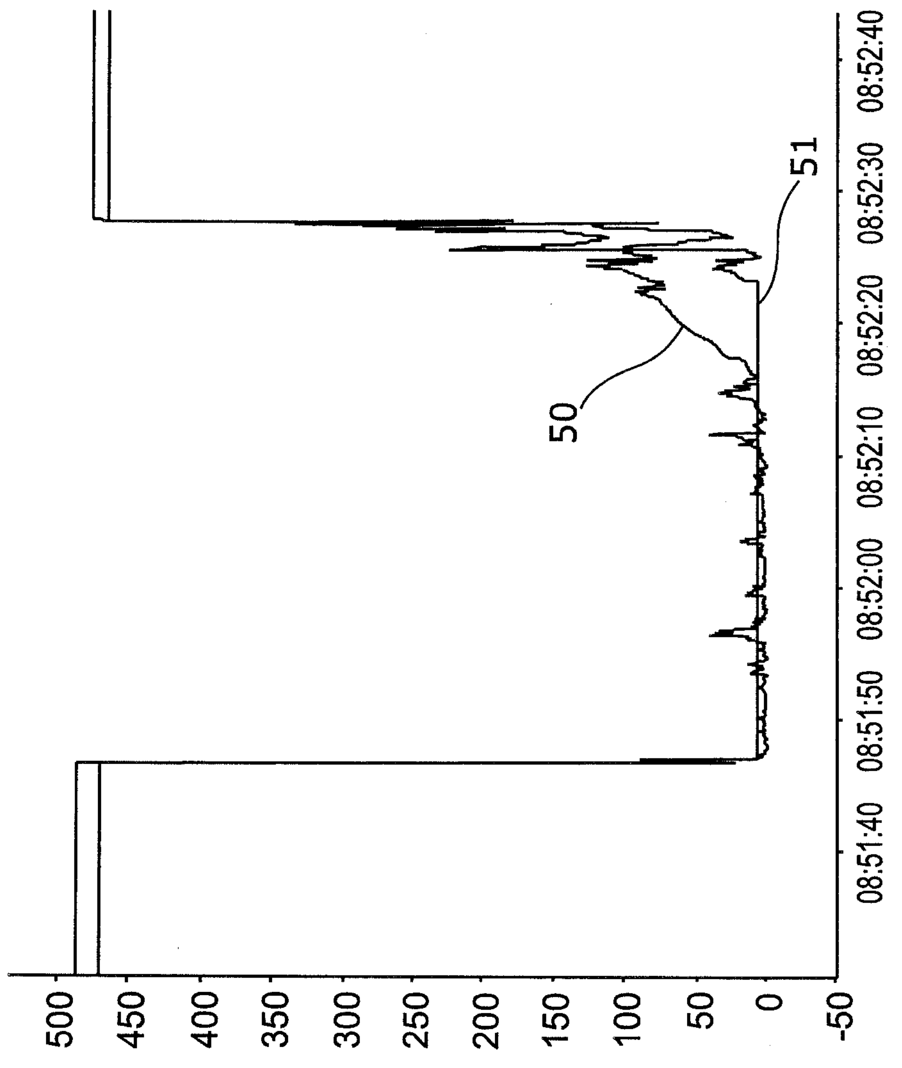


Fig. 12b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50
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Fig. 13

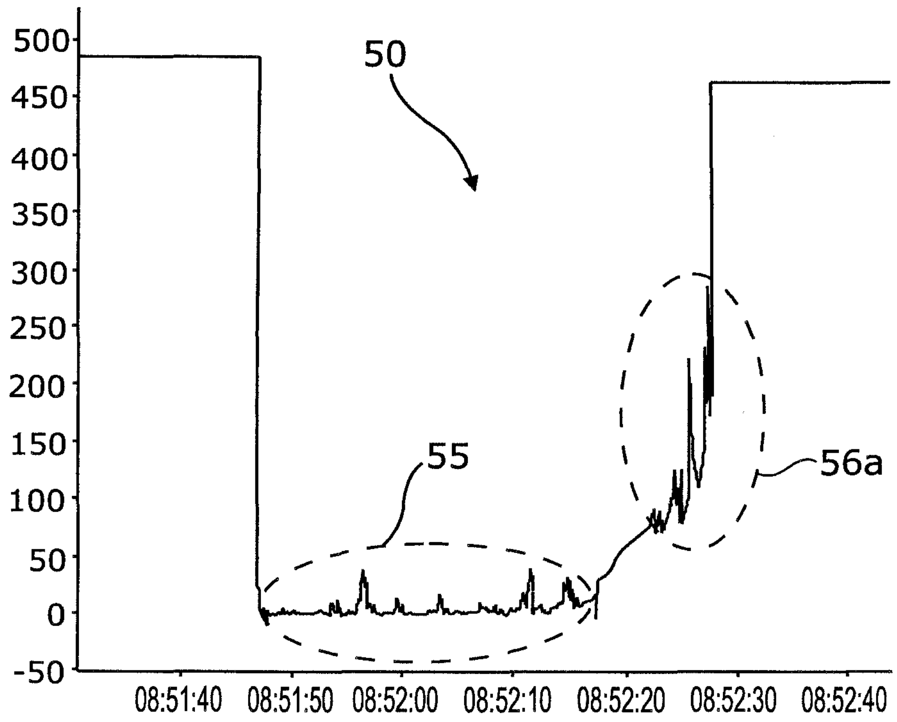

Fig. 13a

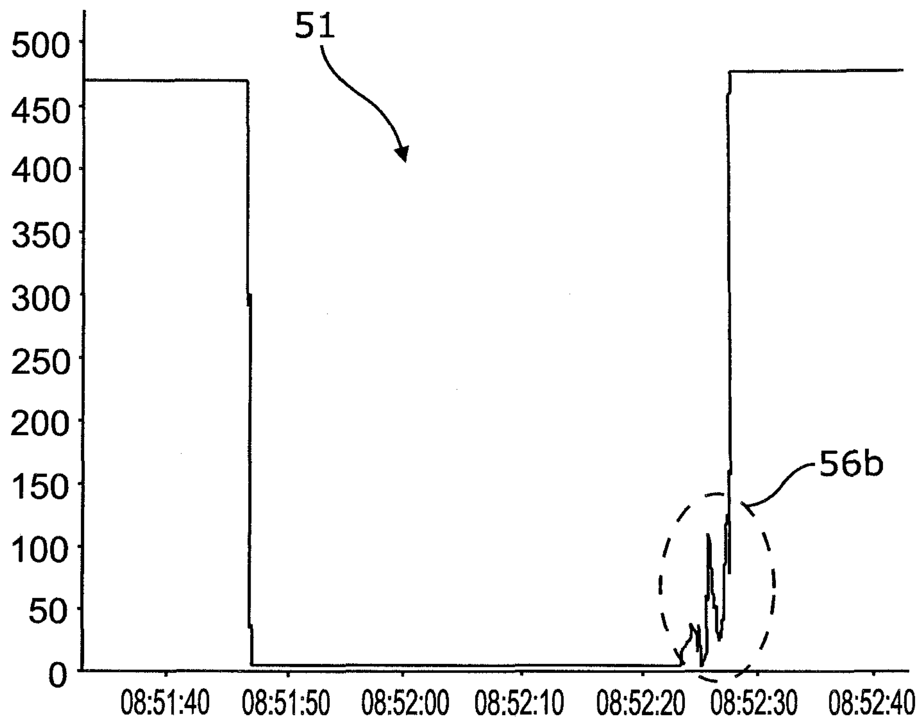

Fig. 13b

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- EP 1746009 A **[0005]**
- WO 2006127066 A **[0005]**