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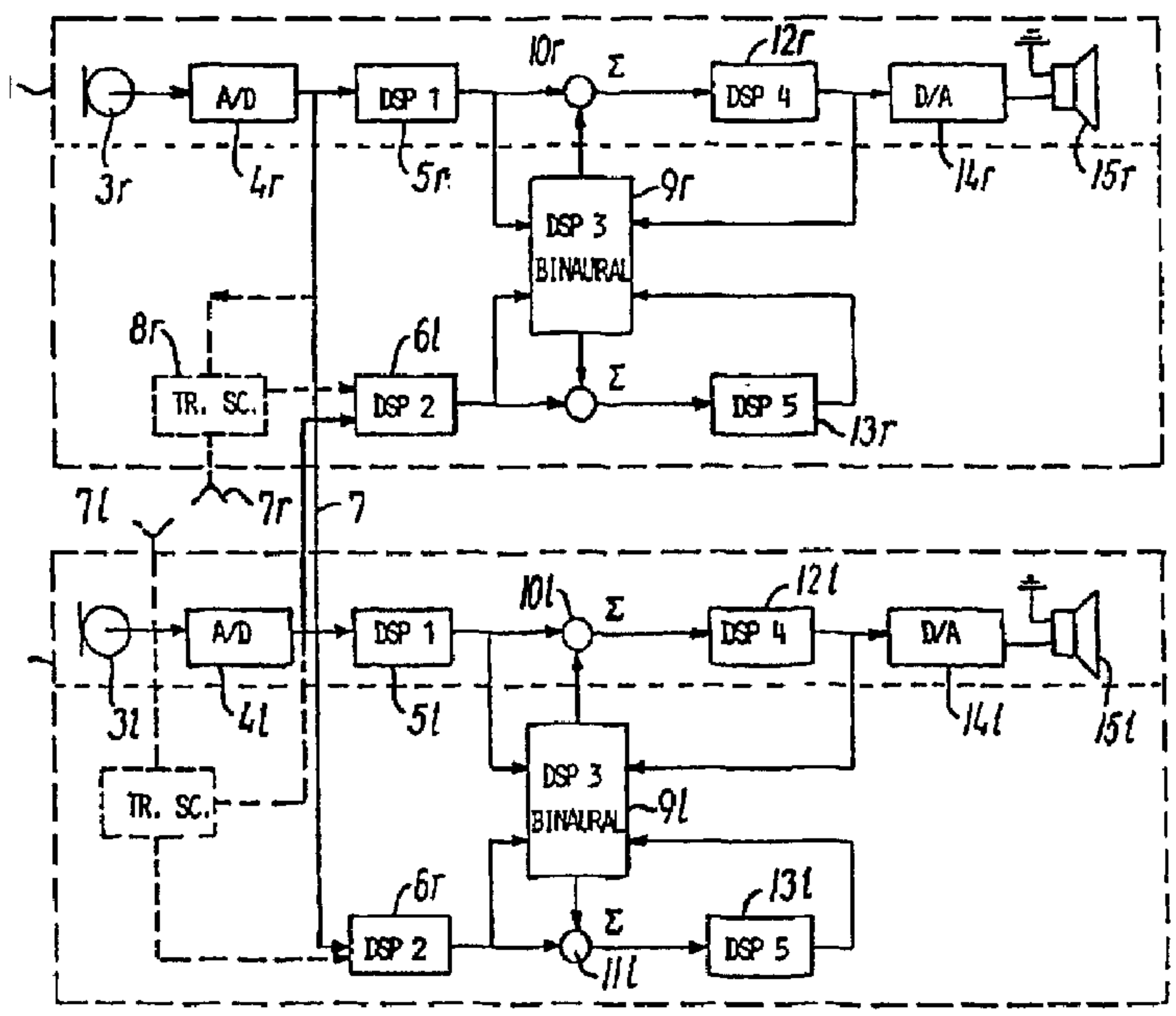

(57) Abrégé/Abstract:
A binaural digital hearing aid system comprises two hearing aid units (1, 2) for arrangement in a user's left and right ear, respectively. Each unit comprises input signal transducer means (3r, 3l), A/D conversion means (4r, 41), digital signal processing means (5r-13r, 5l-13l), D/A conversion means (14r, 14l) and output signal transducer means (15r, 15l). A bi-directional communication link (7) is provided between the units. The digital signal processing means of each unit is arranged to affect a substantially full digital signal processing including individual processing of signals from the input transducer means of the actual unit and simulated processing of signals from the input transducer means of the other unit as well as binaural signal processing and includes at least a first digital signal processor pan (5r, 5l) for processing said internally supplied signal, a second digital signal processor part (6l, 6r) for processing the signal supplied via said communication link (7) and a third digital signal processor part (9r, 9l) to effect common binaural digital signal processing of information derived from the signals processed in said first and second digital signal processor pans, said second digital signal processor part (6l, 6r) in each unit simulating the first digital signal processor part (5l, 5r) in the other unit with respect to adjustment parameters controlling the performance of said first signal processor part in said other unit.

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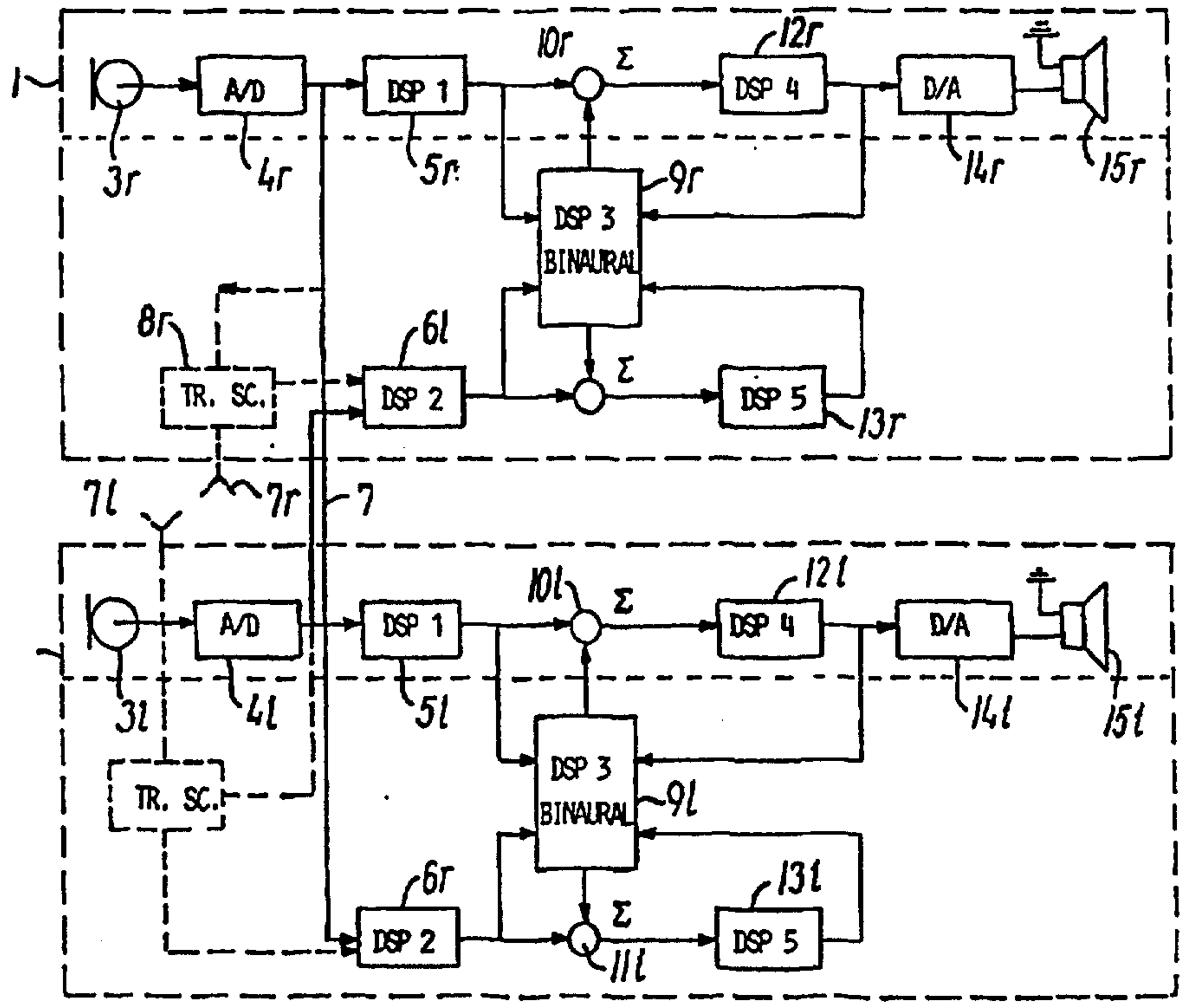
(54) Title: A BINAURAL DIGITAL HEARING AID SYSTEM

(57) Abstract



A binaural digital hearing aid system comprises two hearing aid units (1, 2) for arrangement in a user's left and right ear, respectively. Each unit comprises input signal transducer means (3r, 3l), A/D conversion means (4r, 4l), digital signal processing means (5r–13r, 5l–13l), D/A conversion means (14r, 14l) and output signal transducer means (15r, 15l). A bi-directional communication link (7) is provided between the units. The digital signal processing means of each unit is arranged to affect a substantially full digital signal processing including individual processing of signals from the input transducer means of the actual unit and simulated processing of signals from the input transducer means of the other unit as well as binaural signal processing and includes at least a first digital signal processor part (5r, 5l) for processing said internally supplied signal, a second digital signal processor part (6l, 6r) for processing the signal supplied via said communication link (7) and a third digital signal processor part (9r, 9l) to effect common binaural digital signal processing of information derived from the signals processed in said first and second digital signal processor parts, said second digital signal processor part (6l, 6r) in each unit simulating the first digital signal processor part (5l, 5r) in the other unit with respect to adjustment parameters controlling the performance of said first signal processor part in said other unit.

A Binaural Digital Hearing Aid System

The present invention relates to a binaural digital hearing aid system comprising two hearing aid units for arrangement in a user's left and right ear, respectively, each of the units comprising input signal transducer means for conversion of a received input sound signal into an analog input signal, A/D conversion means for conversion of the analog input signal into a digital input signal, digital signal processing means for processing the digital input signal and generating a digital output signal, D/A conversion means for conversion of said digital output signal into an analog output signal and output signal transducer means for conversion of the analog output signal into an output sound signal perceivable to the user, a bidirectional communication link being provided between the units to connect a point in the signal path between the input signal transducer means and the digital signal processing means in one of the units with a corresponding point in the signal path between the input signal transducer means and the digital signal processing means of the other units.

For persons without hearing impairments the ability to localize sounds in space is defined as binaural hearing ability and is an important part of sound perception. Typically the amplitude of sound received by the ipsilateral ear which is closer to the source of sound, is of greater amplitude than the sound received by the opposite contralateral ear. This difference in sound level, although often small by itself, is of great importance for a human's perception of the direction of an incident sound.

In the human hearing system, binaural sound perception results from a complicated signal processing of sounds arriving at the left and right side ears, in which time/phase and frequency distribution of the sound plays a decisive role. Thus, time/phase differences and frequency enhancement are important for determining directions in the horizontal and vertical planes, respectively.

The customary practice for individuals suffering from a binaural hearing impairment, i.e. a hearing loss affecting both ears, has been to use two separate conventional analog hearing aids adjusted to compensate individually for the hearing loss of the respective ear for which the hearing aid is operative. However, binaural sound perception remains unaffected by this practice, and is typically made even worse by the very use of a hearing aid in both ears.

As a relatively simple solution for the loss of binaural sound perception it has been suggested for each of the two hearing aids of an analog system to use a microphone with a pronounced direction dependent characteristic to provide an analog signal, the level of which changes, when the hearing aid is moved from a position pointing towards the sound source to other positions with a minimum level, when the hearing aid points in a direction at right angles to the direction of the sound source.

In US Patent No. 3,509,289 a different concept for compensation of binaural hearing loss in an analog hearing aid system is disclosed involving the use of cross-coupled automatic gain control (AGC) circuitry for maintaining and enhancing the interaural level difference between contralateral and ipsilateral incident sound. In this system, the gain of each of a first and second amplifying channel is varied inversely with the output of the other channel by separate AGC circuits which are cross-coupled to stabilize the system.

With the introduction of digital signal processing in hearing aids a significant improvement of hearing aid performance has become possible and more advanced proposals for binaural hearing loss compensation have been suggested.

Thus, US Patent No. 5,479,522 discloses a hearing enhancement system comprising in addition to two hearing aid devices for arrangement in the left and right side ears, respectively, a body-worn pack comprising a remote digital signal processor connected to each of the hearing aid devices by a down-link and an up-link for interactive digital processing of the audio signals for each ear based on signals received from both hearing aid devices. The common binaural digital signal processing is determined and limited to attenuation of noise and narrowing of the sound field or adapting the signal level in the two channels. The signals supplied to the common binaural signal processing means are not affected by the individual hearing loss compensation in the two channels.

In addition, this prior art system reduces the comfort by requiring a separate body-worn signal processor in addition to the two hearing aid devices and the physical links between the common binaural processor and the two hearing aid devices in the form of radio communications make the system susceptible to distortion affecting the quality of sound reproduction.

In WO 97/14268, a binaural digital hearing aid system is disclosed in which the need for a separate body-worn remote control processor has been eliminated by the use of two hearing aid devices for arrangement in the left and right side ears. Each hearing aid device incorporates a digital signal processor to which not only the unprocessed audio signal generated by the microphone in the same hearing aid device is supplied, but also the unprocessed audio signal generated by the microphone in the opposite hearing aid device, the latter audio signal from each of the two devices being supplied to the respective opposite device through a bidirectional communication link.

This prior art system can be switched between distinct modes of either full binaural signal processing or performance as a conventional monaural hearing aid, which in one embodiment is done by giving the user the option of disabling the digital signal processor by either physically removing an external digital processing unit or by disabling the digital processor.

In the binaural processing mode of this prior art system nothing is provided that would circumvent the difference in hearing loss and compensation between the two ears. Although, somewhat generalized, the system could be seen as an advanced digital substitute for the above-mentioned relatively simple binaural compensation using microphones with a pronounced direction dependent characteristic.

It is the object of the present invention to provide an improved digital binaural hearing aid system in which the above-mentioned shortcomings of prior art systems have been eliminated to provide for binaural signal processing, which, for persons with a binaural hearing loss, will restore binaural sound perception while taking into account the difference in hearing loss and compensation between the two ears.

According to one aspect of the present invention, there is provided a binaural digital hearing aid system comprising two hearing aid units for arrangement in a user's left and right ear, respectively, each of the units comprising input signal transducer means for conversion of a received input sound signal into an analog input signal, A/D conversion means for conversion of the analog input signal into a digital input signal, digital signal processing means for processing the digital input signal and generating a digital output signal, D/A conversion means for conversion of the digital output signal into an analog output signal and output signal transducer means for conversion of the analog output signal into an output sound signal perceivable to the user, a bidirectional communication link being provided between the units to connect a point in the signal path between the input signal transducer means and the digital signal processing means in one of the units with a corresponding point in the signal path between the input signal transducer means and the digital signal processing means of the other of the units, wherein the digital signal processing means of each unit is arranged to effect a substantially full digital signal processing including individual processing of signals from the input transducer means of one unit and simulated processing of signals from the input transducer means of the other unit as well as binaural signal processing of signals supplied, on one hand, internally from the input signal transducer means of the same unit and, on the other hand, via the communication link from the input signal transducer means of the other unit, the digital signal processing means including at least a first digital signal processor part for processing the internally supplied signal, a second digital signal processor part for processing the signal supplied via the communication link and a third digital signal processor part to effect common binaural digital signal processing of information derived from the signals processed in the first and second digital signal processor parts, the second digital signal processor part in each unit simulating the first digital signal processor part in the other unit with respect to adjustment parameters controlling the performance of the first signal processor part in the other unit.

According to a further aspect of the present invention, there is provided a hearing aid for arrangement in an ear of a hearing impaired person, comprising a microphone for converting a sound input into an electric input signal, an A/D converter for converting the electric input signal into a digital input signal, a link for bidirectional communication with another hearing aid for arrangement in a respective opposite ear of the person, a digital signal processor including a first processor part for processing the digital input signal in order to provide a hearing loss compensation for the respective ear of the user, a second processor part for receiving via the link and input signal from the other hearing aid and for effecting signal processing adapted to provide simulated hearing loss compensation for the respective opposite ear of the user, a third processor part for effecting binaural digital signal processing of information derived from the signals processed in the first and second processor parts to provide a digital output signal, a D/A converter for converting the digital output signal into an analog output signal and an output signal transducer for converting the analog output signal into an output sound signal.

Thereby, in the binaural hearing aid system of the invention each of the hearing aid units for the left and right side ears, respectively, performs in addition to digital signal processing adapted to compensate for the hearing loss of the ear served by the unit, a simulated full digital signal processing of sound signals received by the unit for the opposite ear and adapted to compensate for the specific hearing loss of that ear, as well as a common binaural signal processing taking into account both of the normally different compensation characteristics of both units.

By the advantageous embodiments and modifications of the system, the system can be designed for user operated switching between functioning as a binaural system and a conventional monaural hearing system, and the digital signal processing means in each hearing unit may be programmable to be switchable between different sound environments or listening situations by user operation, whereby programmed performance data for the first signal processing means of one unit is entered for programming of the second signal processing means of the other unit, in which the simulated signal processing of signals supplied from the first unit is carried out.

By the provision of only a single bidirectional communication link between the two hearing aid units, the hearing aid system of the invention is less susceptible to signal distortion and interruption than the prior art systems described above.

Embodiments of the present invention will be further described with reference to the accompanying drawings, in which:

Figure 1 is a schematic block diagram representation of an embodiment of the hearing aid system of the present invention;

Figure 2 is a further detailed representation of the embodiment shown in Figure 1; and

Figure 3 is a block diagram representation of one hearing aid unit of a programmable hearing aid system of the present invention.

The binaural hearing system illustrated in Figure 1 comprises two hearing aid units 1 and 2 intended for arrangement in the user's right and left ears, respectively. The hearing aid units 1 and 2 are identical in structure, but as further explained in the following they will normally have been programmed or otherwise adjusted to provide different hearing loss compensation adapted to the specific hearing impairment of the ear, in which the unit is to be arranged. For the following description identical parts in the two units 1 and 2 will be designated by the same reference numeral followed by "r" and "l", respectively, to indicate the localization of such parts in either the right ear or the left ear unit 1 or 2.

Each of units 1 and 2 comprises input signal transducer means e.g. in the form of one or more hearing aid microphones 3r, 3l which receives sound signals to be processed in the unit and transforms these sound signals into analog electrical signals which are supplied to an A/D converter 4r, 4l for conversion into digital signals.

In the embodiment shown in Figure 1 the digital signal from A/D converter 4r, 4l in each of units 1 and 2 is supplied to a first digital signal processor 5r, 5l which is programmed or otherwise adjusted to perform signal processing functions such as filtering, band-division, amplification, gain control, adjustment, compression, expansion and/or compensation for unlinearities in the microphone or the user's ear channel.

However, to the extent that some of the signal processing functions of processors 5r, 5l may be implemented in the A/D converters 4r, 4l, each of which will then supply a preprocessed digital signal, each of the digital processors 5r, 5l need not be present as a separate unit.

According to the present invention, each of units 1 and 2 also comprises a second digital signal processor 6l and 6r, respectively, which is structurally identical to processor 5r, 5l, but is programmed or otherwise adjusted to perform digital signal processing functions on the signals received by the opposite ear, i.e. processor 6l in unit 1 for the right ear is programmed to provide the specific signal processing intended for the left ear and will thus, in principle, provide the same signal processing as signal processor 5l in unit 2, whereas signal processor 6r in unit 2 will provide the same signal processing as processor 5r in unit 1.

In the embodiment shown in Figure 1 the digital electrical signal from A/D converter 4r, 4l in each of units 1 and 2 is additionally supplied via a communication link 7 to second signal processor 6r, 6l in the other unit, such that in each unit the second signal processor 6l, 6r performs a simulated processing corresponding to the processing by first signal processor 5l, 5r in the other unit. However, as an alternative the analog signals from microphone 3r, 3l, in each of units 1 and 2 could be communicated directly and supplied to A/D conversion in the other unit.

The signal processors 5r, 5l and 6r, 6l will typically be state of the art digital hearing aid processors programmed to perform a relatively sophisticated signal processing with respect to sound/noise separation and user operated adaptability to a number of different sound environments or listening situations.

The communication link 7 between the right and left hearing aid units 1 and 2 is preferably a single bidirectional communication link which may be physically implemented by a cable extending between the two units. The hearing aid units 1 and 2 may be designed for arrangement in the ear (ITE) or behind the ear (BTE). In either case a cable connection between the units may extend around the neck of the user and may eventually be integrated in a necklace or similar piece of jewelry or bijouterie.

Alternatively, the bidirectional communication link 7 may be wireless and, as shown in dashed lines, comprise antennas 7r, 7l connected with appropriate transceiving means 8r, 8l in each unit. For hearing units in ITE design such an antenna may be physically implemented by a relatively short piece of wire or string which in use will project outside the ear and may serve additionally to facilitate withdrawal of the hearing unit from its ITE position.

In each of units 1 and 2 the first and second digital signal processors 5r, 5l and 6l, 6r outputs a processed digital signal which is supplied to a third signal processor 9r, 9l which, in accordance with the present invention performs common binaural digital signal processing of the processed digital signals outputted from the first and second signal processors 5r, 5l and 6l, 6r.

The binaural signal processing in each of the third signal processors 9r, 9l may make use of state of the art binaural processing techniques taking into account differences with respect to amplitude, phase-lag etc., between arrival of incoming sounds at the input transducers of the right and left ear hearing aid units. As a result of this binaural signal processing which according to the present invention is based on information derived from the processed digital signals in both of units 1 and 2, the third signal processor 9l, 9r in each unit outputs processed digital right and left binaural signal parts which in digital adder devices 10r, 10l and 11l, 11r is combined with the processed digital output signal from first signal processor 5r, 5l in the same unit.

In each unit the combined processed digital signals from adder device 10r, 10l may be supplied directly to a D/A converter 14r, 14l for conversion into a processed analog signal which is supplied to an output transducer device in the form of a conventional hearing aid telephone 15r, 15l. As illustrated the processed digital signals from adder devices 10r, 10l and 11r, 11l may optionally undergo a further digital signal processing in fourth signal processors 12r, 12l and fifth signal processors 13r, 13l, respectively, which may include compensation of the specific hearing loss and automatic gain control. From processors 12r, 12l and 13r, 13l feedback signals are also supplied to the binaural processor 9r, 9l.

The processing functions of the fourth and fifth signal processors 12r, 12l and 13r, 13l in each of units 1 and 2 may be implemented in the binaural processor 9r, 9l so that processors 12r, 12l and 13r, 13l may in principle be dispensed with as separate units. The binaural signal processor 9r, 9l may then further be designed to output only the binaural digital signal part intended for the actual unit, i.e., the right ear binaural signal part for unit 1 and the left ear binaural signal part for unit 2. In both cases, the incorporation of the fourth and fifth signal processors either as separate units or in the binaural processor 9r, 9l provides an advantageous possibility, however, for an AGC function and/or hearing loss compensation in the binaural signal processor 9r, 9l by feed-back of the processed digital output signals from both of the fourth and fifth signal processors 12r, 12l and 13r, 13l to the binaural processor 9r, 9l.

Examples of digital signal processors for use in each of units 1 and 2 are disclosed e.g. in EP Patent No. 0 732 036, US Patent No. 5,165,017, US Patent No. 4,531,229 and US patent No. 5,144,675. An advanced signal processing method and device employing so called dynamic AGC has been disclosed in co-pending International patent application publication No. WO 99/34642.

The design and structure of the binaural hearing system of the present invention, by which all information carrying signals in the separate signal channels for the right ear and the left ear sound perception are made available for processing in both of units 1 and 2 not only of the signal actually belonging to the respective side, but also, by simulated processing, of the signal belonging to the other side, opens the possibility of implementing complex and highly sophisticated binaural signal processing to restore binaural hearing ability without significant complication of the structure. In fact, both hearing aid units 1 and 2 may be identical in structure and equipped with identical components like converters, signal processors etc.

Whereas the various signal processors in each of units 1 and 2 have been illustrated and described as separate processors they may advantageously be incorporated as separate processing parts of a common single digital processor such as a microprocessor.

The embodiment of the present hearing aid system shown in Figure 2 serves to illustrate the degree of complexity of binaural signal processing that can be implemented in each of the right and left ear hearing aid units 16 and 17 with a single bidirectional communication link 28 between the two units.

Using the same distinction as to reference numerals between the right and left ear units as used for the embodiment in Figure 1 only the structure and function of the right ear unit 16 will be explained in the following.

The unprocessed analog signal from microphone 18r is preamplified and converted to digital form in preamplifier and A/D converter 19r and processed to compensate for unlinearity of the microphone and the sound perception in the ear in linearity control unit 20r, from which a preprocessed digital signal is supplied, on one hand to a band divider filtering unit 21r in the signal processing channel for the right ear and, via the bidirectional communication link 28 to a band divider filtering unit 21rs in the processing part of the left ear unit 17 performing the simulated right ear signal processing.

In the band divider filtering unit 21r the incoming preprocessed digital signal is split into a number of frequency bands, each of which is further processed in a noise filtering unit 22r and a processing unit 23r in which the signal is amplified in accordance with the compensation characteristic adapted to compensate for the specific hearing loss of the right ear.

As for the embodiment in Figure 1 each of the two hearing aids comprise, in addition to the signal processing channel for the ear in which the unit is arranged, a separate signal processing channel effecting a simulated signal processing corresponding to the signal processing in the other unit. In the embodiment shown in Figure 2 this simulated processing channel comprises for the right ear hearing aid unit 16 processing units 21ls, 22ls and 23ls effecting the same processing functions as processing units 21r, 22r and 23r for the right ear compensation, but adjusted to the specific characteristics for the left ear compensation effected in the left ear hearing aid unit 17.

The left ear hearing aid unit 17 is identical in structure to the right ear hearing aid unit 16 and comprises the left ear signal processing channel with processing unit 19l and 20l and filtering and compensation units 21l, 22l and 23l as well as the simulated right ear processing channel including units 21rs, 22rs and 23rs.

In each of hearing aid units 16 and 17 binaural signal processing may be effected in two processing units 24r, 24l and 25r, 25l. Thus, in the right ear hearing aid unit 16 a first binaural processing unit 24r may receive the band divided output signals from filtering unit 21r in the right ear processing channel as well as from filtering unit 21ls in the simulated left ear processing channel and provides correction signals effecting signal scaling in processing units 22r and 22ls and a second binaural processing unit 25r may effect further binaural signal processing on incoming signal from the first binaural processing unit 24r as well as from processing units 22r, 22ls and 23r, 23ls.

Finally in each of hearing aid units 16 and 17 the output signal from processing unit 23r, 23l in the right and left ear processing channel, respectively, and the binaural output signal from the second binaural processing unit 25r, 25l is reconverted into analog form in an output processing unit 26r, 26l and supplied to an output transducer such as a conventional hearing aid telephone 27r, 27l.

In each of hearing aid units 16 and 17 all of processing units 22 to 25 may be designed for automatic gain control (AGC), e.g. as disclosed in the above-mentioned co-pending International patent application publication No. WO 99/34642.

In each of hearing aid units 16 and 17 the processing units 21 to 25 are thus interconnected via a multiplicity of internal information and control signal lines, whereas the only external connection to the other hearing aid unit is via the single directional communication link 28.

According to a particular aspect of the present invention the signal lines connecting the processing units 21 to 23 of the right and left ear processing channels and the simulated left and right ear processing channels to the binaural processing units 24 and 25 may be opened and closed or activated and deactivated by control of appropriate switching means, not illustrated, whereby an advantageous adjustment flexibility is obtained with a smooth transition ranging from full binaural signal processing approximating the sound information processing of the human brain via a more simple binaural sound level control to conventional monaural sound reproduction, contrary to the separation of the processing units for normal and binaural processing in the prior art system of WO 97/14268 explained above.

The signals supplied in each of the right and left ear hearing aid units to the binaural signal processing in units 24 and 25, as illustrated in Figure 2, may be microphone signals which have been preprocessed by conversion into digital form and correction of frequency and/or level distortions caused by unlinearities in the microphone circuits and/or following from the arrangement in the user's ear channel. Preferably, the incoming signals for the binaural processing have been filtered to the desired frequency band width.

Moreover as shown in Figure 2 the preprocessed microphone signal supplied from each of hearing aid units 16 and 17 to the simulated processing channel of the other unit may be limited, e.g. by compression in an additional compressor unit 28r, 28l, to reduce the dynamic range, the band width and/or the number of samplings, thereby reducing the amount of data or information to be processed by the simulated processing. A similar signal limitation may also be provided, e.g. by an additional compressor unit 29r, 29l for the signals supplied in each hearing unit from the signal processing channel for the right or left ear, respectively, to binaural signal processing. In either case the processing units, to which such compressed signals are supplied, must be designed for processing these signals.

The binaural signal processing effected by processing units 24 and 25 may comprise a level correction, by which the gain in the hearing aid unit, right or left, receiving the weakest incoming sound signal is controlled on the basis of the incoming sound signal at the other hearing aid unit as represented, by the preprocessed microphone signal communicated therefrom via communication link 28 for simulated signal processing. Thereby, the sound level ratio between sounds received by the right and left ears, respectively, and the spatial information provided thereby may be maintained also for hearing aid units with AGC, since AGC control can be effected on the basis of the strongest processed signal in the right or left ear units 16 and 17.

The complexity allowed for the internal signal processing in each of hearing aid units 16 and 17 would also allow a compensation for time delays introduced by the signal communication via communication link 28, if necessary.

For hearing aids illustrated in Figure 2 sound or signal processing occurs in a number of separate frequency bands with automatic gain control in each band. The processing complexity and/or capacity involves data or information transfer between the real and simulated processing channels in each unit, to provide for equal adaptation of the gain control of these processing channels. The overall transfer function of each hearing aid unit may be adapted to take into account sound spectrum differences occurring at the right and left sides, thereby processing the frequency distribution in the spectra of sounds received at the right and left ears. This is very important for the localization of a sound source in space.

Since, in each of the right and left ear hearing aid units 16a and 17 of Figure 2 all processing units 19r - 23r, 19l - 23l for the actual right or left ear signal processing channel and all processing units 21ls - 23ls, 21rs - 23rs for the simulated signal processing channel are programmed or otherwise adjusted to the specific processing parameters for the right and left ear signal processing, the binaural signal processing in each side interprets the specific hearing loss characteristics of both sides up to or even beyond the output signal transducer 26r and 26l. To accomplish this, the binaural signal processing effected in the right and left ear hearing units 16 and 17 will typically be mirror images of each other in order to restore the actual sound level and sound spectrum differences between incoming sounds at the right and left ears.

An added advantage of binaural signal processing in each of the two hearing units of the system according to the present invention is sophisticated noise or feedback suppression. Noise or feedback suppression is achieved when tone signals deviating from the overall sound image are effectively suppressed without suppression of tone signals present in the overall sound signal or in the right and left side at the same time. This can be accomplished by including in the binaural sound processing unit a feedback suppression system to which a residual feedback signal representing the different feedback signals from the actual and simulated sound processing channels is supplied. By means of such a feedback suppression it is possible for the hearing aid system of the present invention to distinguish between howl and information sound signals with similar characteristics such as a tone from a flute solo in classical music composition, an alarm or signalling tones such as walk/stop beeps at traffic lights.

In each of hearing aid units 16 and 17 the performance of each of the signal processing units 21r - 23r, 21l - 23l in the real signal processing channel as well as the performance of each of the processing units 21ls - 23ls, 21rs - 23rs in the simulated processing channel is controlled by adjustment parameters or data adapted to the specific compensation requirements of the right and left ears, respectively.

According to the present invention adjustment parameters may be individually programmable to compensate for the user's specific hearing impairment with respect to the right and left ears. The hearing aid system may be supplied with a standard adjustment to permit individual programming to be effected by a hearing aid fitter, as is customary practice in individual user adjustment of hearing aids.

Moreover, the adjustment parameters may be organized in different programme settings to permit operation of the hearing aid system in different modes ranging from fully binaural to simple monaural operation of the hearing aid units. In addition, the adjustment parameters may be organized in different programme settings to permit adaption of the hearing aid system to varying sound environments or listening situations.

Figure 3 shows one of the hearing aid units in the system illustrated in Figure 2. The right ear hearing aid unit 16 in Figure 3 is programmed by means of a performance and programme memory 30 in which all programmable adjustment parameters for a number of specific performance programmes are entered and may be selected from a selection unit 31, which may be user operated and/or operated from a sound signal analyzer 32 to effect programme selection automatically in response to specific sound signal conditions.

Optionally, at least one of hearing aid units 16 or 17 may include means for calculation of intermediate settings between at least two consecutive performance programme settings, in which case such intermediate settings will be selectable from the selection unit 31.

As a result of the structure and organization of hearing aid units 16 and 17 to effect not only the actual signal processing for the ear in which the unit is arranged, but also the simulated processing for the opposite ear, memory 30 will contain all adjustment parameters needed for the signal processing for both sides. The programming of the hearing aid system may be either effected by the user entering adjustment parameters or automatic activation of performance programmes stored in memory 30 of one of the hearing aid units 16 and 17. Transfer of adjustment parameters for the processing units of the other hearing aid unit occurs via the communication link 28 in an adjustment or initiation mode activated at each change of performance programme. Ultimately this makes possible to operate the system according to the invention by a master-slave principle, in which one of the hearing aid units would function as a master unit and take control of the other unit, functioning as a slave unit. The memory 30 of the slave unit would then contain the information or parameters needed for it to actually function as a slave unit.

Alternatively, various kinds of intermediate or mixed organization schemes can be envisioned for example designing both hearing units with user operated as well as automatic programme selection. This could provide for consensus operation in situations where one unit would try to shift automatically to a specific programme matching prevailing sound signal conditions. For example, an exchange of actual adjustment parameter settings between the two units could occur via the communication link 28 to enable a decision to be made in one of the units as to whether the programme selected by the other unit should be effected for both units.

In each of the two units synchronization means 33 may further be provided for the exchange of synchronization information between the signal processing parts of the two units via the communication link 28. Such synchronizing information may be derived from signals otherwise transferred between the two units or may be generated as separate synchronizing signals.

User operability may advantageously be effected by wireless remote control from a separate control unit carried by the user. This is suitable, in particular, for embodiments in which wireless transmission is already used for the bidirectional communication link between the two hearing aid units.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A binaural digital hearing aid system comprising two hearing aid units for arrangement in a user's left and right ear, respectively, each of said units comprising input signal transducer means for conversion of a received input sound signal into an analog input signal, A/D conversion means for conversion of said analog input signal into a digital input signal, digital signal processing means for processing said digital input signal and generating a digital output signal, D/A conversion means for conversion of said digital output signal into an analog output signal and output signal transducer means for conversion of said analog output signal into an output sound signal perceivable to the user, a bidirectional communication link being provided between said units to connect a point in the signal path between the input signal transducer means and the digital signal processing means in one of said units with a corresponding point in the signal path between the input signal transducer means and the digital signal processing means of the other of said units, wherein the digital signal processing means of each unit is arranged to effect a substantially full digital signal processing including individual processing of signals from the input transducer means of one unit and simulated processing of signals from the input transducer means of the other unit as well as binaural signal processing of signals supplied, on one hand, internally from the input signal transducer means of the same unit and, on the other hand, via said communication link from the input signal transducer means of the other unit, said

digital signal processing means including at least a first digital signal processor part for processing said internally supplied signal, a second digital signal processor part for processing the signal supplied via said communication link and a third digital signal processor part to effect common binaural digital signal processing of information derived from the signals processed in said first and second digital signal processor parts, said second digital signal processor part in each unit simulating the first digital signal processor part in the other unit with respect to adjustment parameters controlling the performance of said first signal processor part in said other unit.

2. A hearing aid system as claimed in claim 1, wherein said bidirectional communication link is a wireless transmission link, transceiving means and antenna means being provided in each of said hearing aid units.

3. A hearing aid system as claimed in claim 2, wherein said antenna means in each hearing unit comprises a short piece of antenna wire projecting externally from an ear mold arranged in an in the ear (ITE) or completely in the canal (CIC) position and acting simultaneously as a withdrawal string.

4. A hearing aid system as claimed in any one of claims 1 to 3, wherein in at least one of said hearing aid units adjustment parameters for processing units in an actual signal processing channel effecting signal processing adapted to the ear in which the unit is arranged as well as further adjustment parameters for the

simulated signal processing channel effecting said simulated signal processing adapted to the ear in which the other unit is arranged are entered into a memory.

5. A hearing aid system as claimed in claim 4, wherein said memory further includes performance programme settings to provide varying operation modes ranging from fully binaural signal processing to simple monaural signal processing in the hearing aid units or provide adaptation of system performance to different sound environments or listening situations or both.

6. A hearing aid system as claimed in claim 5, wherein at least one of said hearing aid units include means for calculation of intermediate settings between at least two consecutive performance programme settings.

7. A hearing aid system as claimed in claim 5 or 6, wherein a programme selection means for said performance programme settings including said intermediate settings are user operated or automatically activated or both on the basis of incoming sound signal analysis.

8. A hearing aid system as claimed in claim 7, wherein said selection means are remotely controlled by wireless transmission of control signals.

9. A hearing aid system as claimed in any one of claims 5 to 8, wherein said memory is provided in one hearing aid unit only acting as a master unit, said bidirectional communication link being designed for transfer of adjustment parameter settings from said one

unit to the other unit acting as a slave unit.

10. A hearing aid system as claimed in any one of claims 6 to 8, wherein each of said hearing aid units is provided with said memory and said programme selection means, said selection means being designed in both units for user operation as well as automatic activation, said bidirectional communication link being designed for exchange of parameter settings between the two units and one of the units including decision means to provide for a consensus control of the system.

11. A hearing aid system as claimed in any one of claims 1 to 10, wherein the binaural signal processing functions in each of the two hearing aid units are mirrored with respect to the binaural signal processing functions in the other unit to take account of sound level or sound spectrum differences between incoming sound signal at the right and left ear hearing aid units or both.

12. A hearing aid system as claimed in claim 11, wherein the binaural signal processing part of each of said hearing aid units comprises a feedback howl suppression system providing howl suppression by processing of a residual signal representing the difference between feedback signals in the actual and simulated signal processing channels.

13. A hearing aid system as claimed in any one of claims 1 to 12, wherein in each of the hearing aid units means are provided for limitation.

14. A hearing aid system as claimed in claim 13, wherein said means for limitation are provided by compression of the signals supplied from said first and second processor parts to said third processor part.

15. A hearing aid system as claimed in any one of claims 1 to 14, wherein means are provided in each of the two hearing aid units for exchange of synchronization information between the signal processing parts of the two units.

16. A hearing aid system as claimed in claim 2, wherein said antenna means in each hearing unit comprises a short piece of antenna wire, which also provides a withdrawal string.

17. A hearing aid system as claimed in claim 1, wherein limitation means are provided in each of the hearing aid units.

18. A hearing aid system as claimed in claim 17, wherein said limitation means comprises means for compression of the signals supplied from said first and second processor parts to said third processor part.

19. A hearing aid for arrangement in an ear of a hearing impaired person, comprising a microphone for converting a sound input into an electric input signal, an A/D converter for converting the electric input signal into a digital input signal, a link for bidirectional communication with another hearing aid for arrangement in a respective opposite ear of the person, a digital signal

processor including a first processor part for processing said digital input signal in order to provide a hearing loss compensation for the respective ear of the user, a second processor part for receiving via said link an input signal from said other hearing aid and for effecting signal processing adapted to provide simulated hearing loss compensation for the respective opposite ear of the user, a third processor part for effecting binaural digital signal processing of information derived from the signals processed in said first and second processor parts to provide a digital output signal, a D/A converter for converting the digital output signal into an analog output signal and an output signal transducer for converting the analog output signal into an output sound signal.

20. The hearing aid according to claim 19, wherein said bidirectional communication link comprises a wireless transceiver and an antenna.

21. The hearing aid according to claim 19, comprising a memory for storing performance programme settings for said first processor part as well as for said second processor part in order to provide various operation modes ranging from fully binaural signal processing to simple monaural signal processing.

22. The hearing aid according to claim 21, wherein said memory stores performance programme settings to provide adaptation of system performance to different sound environments.

23. The hearing aid according to claim 21, comprising an automatic programme selection means for selecting among said performance programme settings on the basis of incoming sound signal analysis.

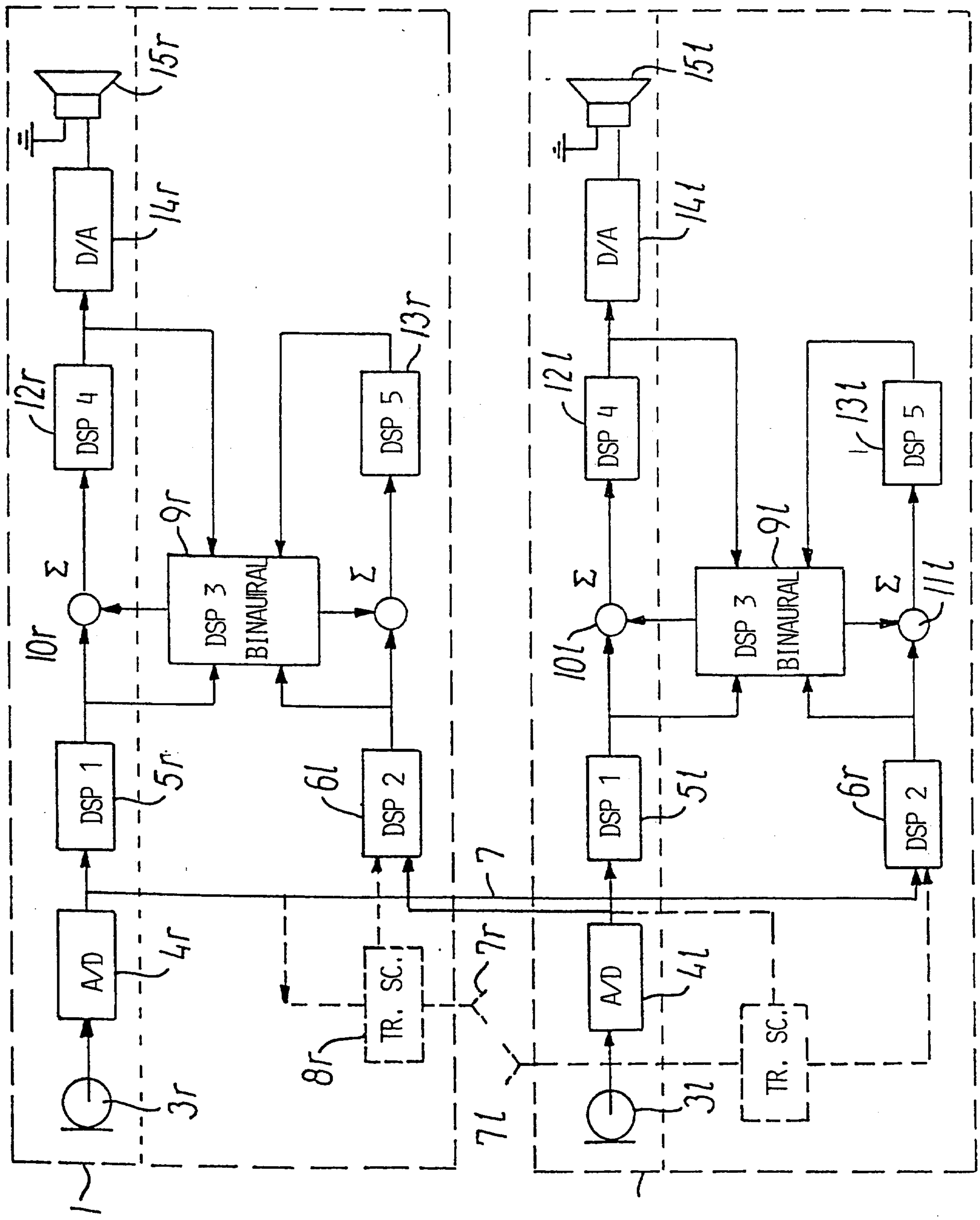
24. The hearing aid according to claim 19, wherein said bidirectional communication link is designed for exchange of parameter settings.

25. The hearing aid according to claim 19, wherein said bidirectional communication link is designed for exchange of synchronization information.

26. The hearing aid according to claim 19, wherein said third processor part comprises a feedback howl suppression system providing howl suppression by processing of a residual signal representing the difference between feedback signals in the first processor part and in the second processor part.

27. The hearing aid according to claim 19, wherein said signal processor comprises means for compensating for time delay introduced by the signal communication via said link.

FIG.1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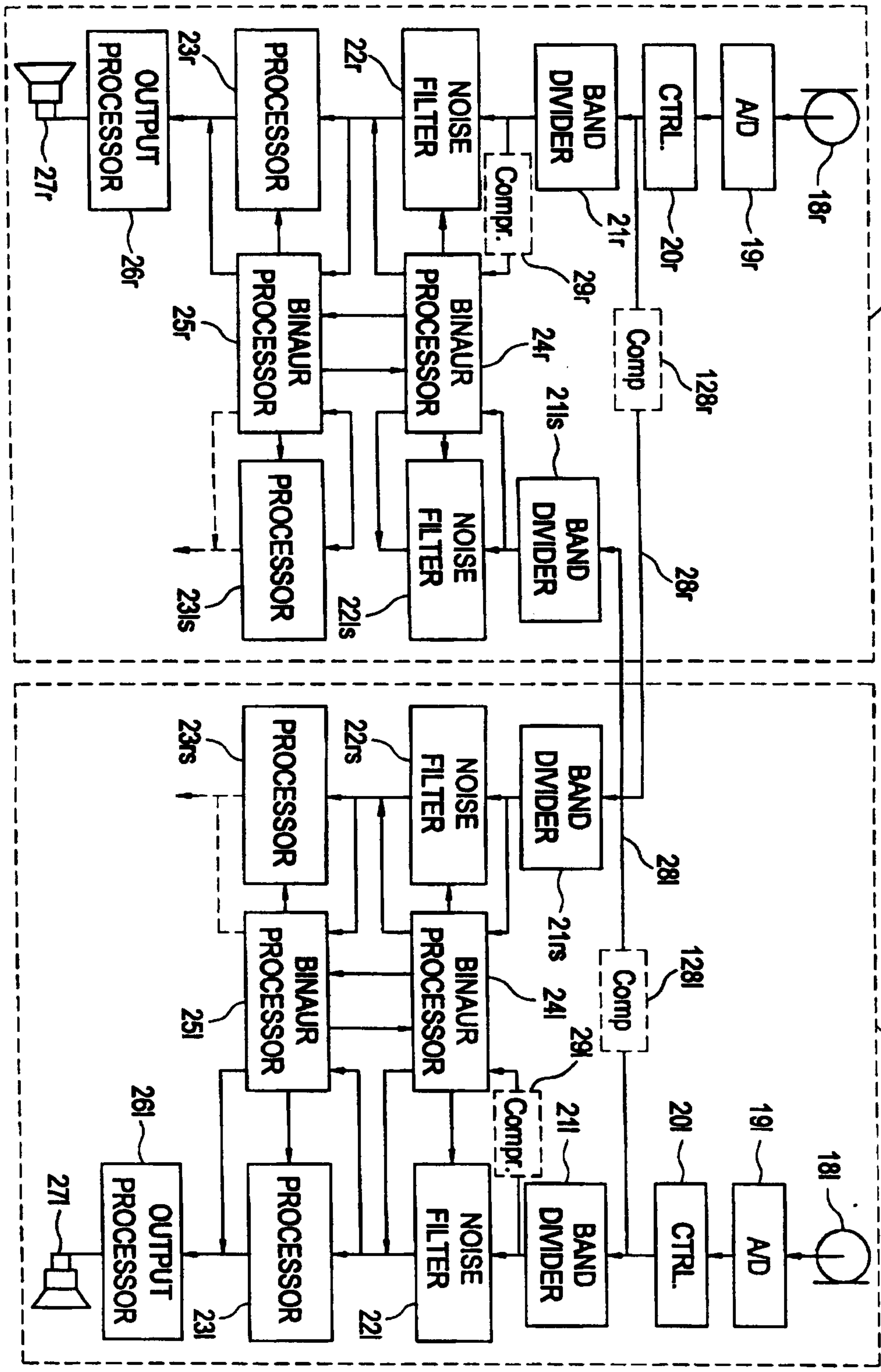
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FIG. 2

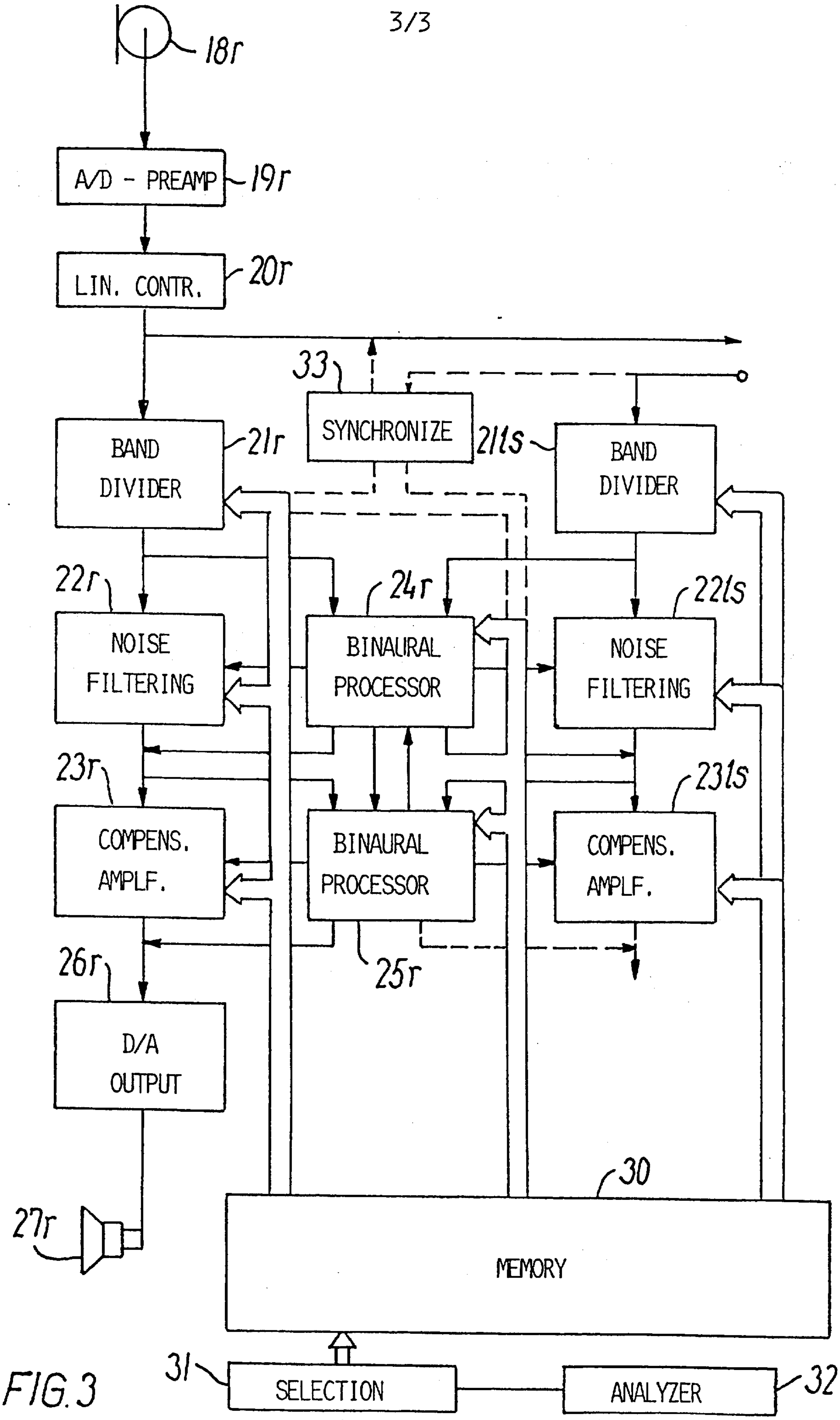
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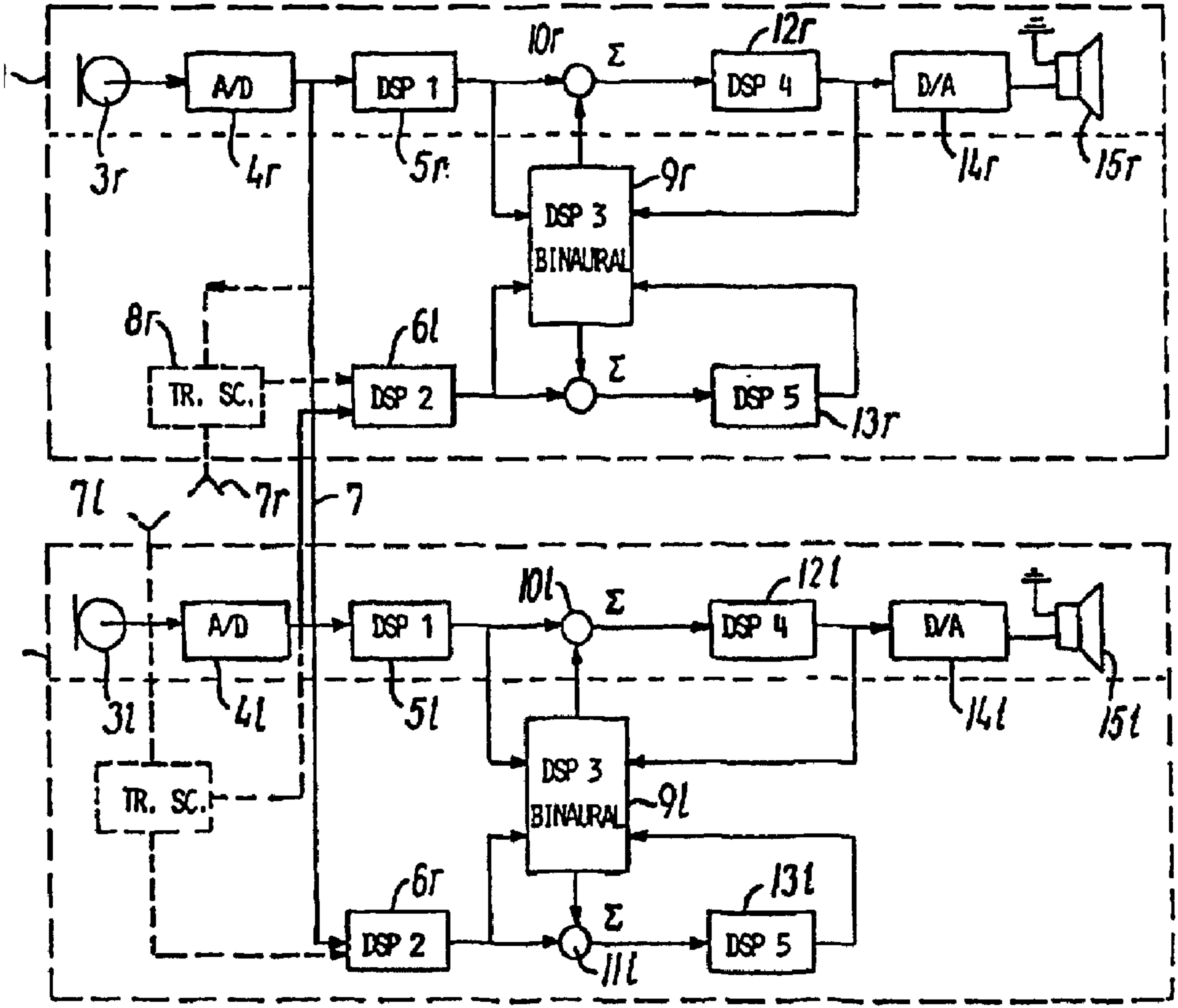
FIG. 3



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