Title of the Invention: Audio amplifier
Abstract Title: Audio amplifier with output limiting circuit, suitable for use with a regulated power supply

An audio amplifier 100 comprises a signal limiting circuit 101 coupled to a power amplifier 103 possibly via a DAC 108. The power amplifier 103 operates from a power supply unit 102 which may produce a load-independent output voltage, e.g. by regulation. The power amplifier 103 amplifies a signal 152 based on the level-limited audio signal 150 and provides a level-limited audio signal 154 to a load 122. The limiting circuit 101 produces an audio signal 150 which is limited depending on the load. The limiting circuit may thus receive information about the voltage and the current in the load via ADCs (fig.2 104a&b). The limiting circuit may operate on the basis of a model (fig.3) of a power supply unit in which the output voltage falls under load, as in a conventional amplifier supply. However, the arrangement allows the amplifier to operate with power supply units in which the output voltage does not fall under load, while also protecting the amplifier against excessive output power. The arrangement allows the tonal effects of power limiting to be dependent only on the design of the limiting circuit 101 and not on the power supply 102.
The invention relates to an audio amplifier and a method for amplifying an audio signal.

An audio amplifier normally comprises the two fundamental components of a power amplifier and a power supply unit. For some years, audio amplifiers have additionally also been equipped with signal processing units, what are known as digital signal processors (DSPs). Furthermore, the demands on the possible output power of audio amplifiers for professional use are becoming greater and greater. Audio signals are typically rather pulsed. That is to say that they have high peak values with a simultaneously relatively low RMS value. As a result, the high powers demanded from the audio amplifiers are only ever needed for a relatively short time. This property is taken into account when designing the power electronics assemblies for an audio amplifier, and said power electronics assemblies are thus able to deliver high voltages and currents on a short-term basis. On a permanent basis, these high powers overtax the power electronics assemblies, which can be destroyed on account of overheating, for example. The current supply line is normally protected from overload by a circuit breaker, which disconnects the supply of current and hence the audio amplifier in the event of excessive loading.

In order to prevent the power electronics assemblies of an audio amplifier from being destroyed, it is therefore necessary for the power to be reduced in the course of operation when the power becomes excessive. Frequently, this is accomplished by using power supply units in which the output voltage falls under load. This decreases the supply voltage for the power amplifier, and the maximum output voltage of the power amplifier is reduced. Usually,
an audio amplifier drives an electrodynamic loudspeaker, the impedance of which is more or less constant. The reduction in the output voltage therefore also reduces the output power and hence the power loss in the audio amplifier and at the same time the power draw on the power supply system.

[0004] However, a disadvantage in this case may be that the power reduction affects the tonal properties of the audio amplifier, specifically depending on the power supply unit used. A further disadvantage may be that only specific power supply units matched to the characteristics of the amplifier may be used.

[0005] An object on which the invention is based can therefore be considered that of providing an audio amplifier which has protection against excessive output power. A particular aim is for the audio amplifier also to be able to be operated with power supply units in which the output voltage does not fall under load.

[0006] The object on which the invention is based is achieved by the features of the independent claims. Advantageous refinements and developments of the invention are the subject matter of the dependent claims.

[0007] One concept on which the invention is based is to emulate the fall in the output voltage of the power supply unit under load, which is known in the prior art, in a signal limiting circuit connected upstream of the power amplifier, so that the audio signal entering the power amplifier is already limited depending on the load and hence there is no longer any need for a power supply unit that performs the load-dependent limiting.

[0008] Hence, the audio amplifier can also be operated with a power supply unit in which the output voltage does not fall under load, and an output signal which is reduced under load is nevertheless
produced, as required. The demands on the power supply unit are decoupled from the demands on the signal limiting, which are now taken into account by a suitable design of the signal limiting circuit. Hence, when designing the power supply unit, it is no longer necessary to pay attention to any disadvantageous influencing of the tonal properties during signal limiting. A further advantage is that when the components of the signal limiting circuit are implemented in software, for example on a digital signal processor (DSP), the hardware components of the audio amplifier can be designed independently of the design of the software which brings about the signal limiting.

[0009] In one embodiment, the signal limiting circuit is in the form of a digital signal processor (DSP), and the fall in the output voltage from the power supply unit is calculated in the form of a model in the DSP. Specifically, a model of a power supply unit is programmed into the DSP of the audio amplifier. The power which is output by the audio channel or the audio channels is captured by the DSP, and the state of the power supply unit model is calculated in real time. The design of the model now allows a falling output voltage from a power supply unit to be simulated and hence the output power to be reduced. This method allows the design of audio amplifiers with a briefly high output power even with power supply units in which the output voltage does not fall under load, for example because they are corrected. Furthermore, the tonal influences of the power reduction are no longer dependent on the actual physical power supply unit that is used, but rather are now dependent only on the design of the model which is in the DSP. This makes it a simple matter to port a desired tonal response to other audio amplifiers or to replace the power supply unit within an appliance, i.e. audio amplifier, with another without having to accept tonal influences.
[0010] The invention is explained by way of example below using exemplary embodiments with reference to the drawings, in which:

Figure 1 shows a block diagram of an audio amplifier based on an exemplary embodiment of the invention;

Figure 2 shows a block diagram of an audio amplifier based on an exemplary embodiment of the invention;

Figure 3 shows a block diagram of a digital signal processor in an audio amplifier based on an exemplary embodiment of the invention;

Figure 4 shows a block diagram of a digital signal processor in an audio amplifier based on an exemplary embodiment of the invention; and

Figure 6 shows a schematic illustration to explain a method for amplifying a digital audio signal based on an exemplary embodiment of the invention.

[0011] Figure 1 shows a block diagram of an audio amplifier 100 based on an exemplary embodiment of the invention. The audio amplifier 100 comprises a signal limiting circuit 101 and a power amplifier 103. The signal limiting circuit 101 has an input 140, in order to receive an audio signal 120, and an output 142, in order to provide a limited audio signal 150 at said output. The audio amplifier 100 is coupled to an audio source 132 which emits an audio signal which is received by the signal limiting circuit 101 as an audio signal 120.
[0012] The audio signal 120 is limited in the signal limiting circuit 101 depending on the load, i.e. driving a load 122, for example a loudspeaker or a loudspeaker array, with a signal which is based on the limited audio signal 150 involves the limited audio signal 150 being reduced in the event of excessively high powers appearing. This corresponds to the response of a power supply unit in which the output voltage falls under load. When a load 122 is operated on the audio amplifier 100, the output power of said load is therefore reduced in comparison with an audio amplifier without signal reduction, which means that the load is effectively prevented from being destroyed or damaged. The load-dependent limiting of the audio signal 120 can be adjusted in the signal limiting circuit 101 by a model of a power supply unit in which the output voltage falls under load, as illustrated by the exemplary embodiments shown in Figures 3, 4 and 5. This virtually relocates the load-dependent characteristic of such a power supply unit into the signal limiting circuit 101, as a result of which the power amplifier 103 can be operated with any desired power supply unit 102, particularly including the power supply units in which the output voltage does not fall under load, for example because they have a control loop which counteracts such a response. In this case too, the signal limiting circuit 101 ensures that when the load 122 is applied the limited audio signal 150 is effectively limited depending on the load 122.

[0013] The signal limiting circuit 101 may comprise a digital signal processor which receives a digital audio signal 120 and limits the digital audio signal 120 to the limited audio signal 150, which is then available as a limited digital audio signal 150. The signal limiting circuit 101 may comprise a digital microcontroller or microprocessor which receives a digital audio signal 120 and limits the digital audio signal 120 to the limited audio signal 150, which is then available as a limited digital audio
signal 150. The signal limiting circuit 101 may also comprise both a digital signal processor and a digital microcontroller, which together limit the digital audio signal 120 to the limited audio signal 150. In these cases, the load-dependent limiting already takes place in the digital domain rather than in the analogue domain first, as in ordinary audio amplifiers, which means that the power loss on the analogue components is reduced accordingly.

[0014] The signal limiting circuit 101 may also have analogue components which receive an analogue audio signal 120 and limit the analogue audio signal 120 to the limited audio signal 150, which is then available as a limited analogue audio signal 150. By way of example, analogue components may comprise operational amplifiers and comparators. By way of example, analogue limiting can be implemented by a comparator which compares the analogue audio signal 120 with a load-dependent threshold value and performs load-dependent limiting (based on the load-dependent threshold value) in the event of said threshold value being exceeded.

[0015] The power amplifier 103 receives a signal 152 which is based on the limited audio signal 150. A digital-to-analogue converter 108 is optionally connected into the signal path between the signal limiting circuit 101 and the power amplifier 103 in order to convert the limited audio signal 150 provided by the signal limiting circuit 101 into the signal 152. By way of example, such a digital-to-analogue converter 108 is necessary when the signal limiting circuit 101 has a digital signal processor or a microprocessor which performs the limiting and delivers a limited digital audio signal 150. Optionally, there may also be further signal processing units connected in the path between the signal limiting circuit 101 and the power amplifier 103, for example filter and averaging stages or preamplifiers. In all configurations, however, the signal 152 is based on the limited audio signal 150, i.e. the limited audio signal 150 is used to
produce the signal 152. Preferably, the power amplifier 103 is an analogue stage and the signal 152 which the power amplifier 103 receives is an analogue signal. The power amplifier 103 amplifies the signal 152 based on the limited audio signal 150 and provides it as a level-limited audio signal 154, i.e. an audio signal that has the voltage level limited, at an output 146.

[0016] The audio signal 154 at the output of the audio amplifier 100 is therefore limited in voltage level so as to be able to operate the load 122 at limited power. That is to say that the voltage in the load 122 is converted into a power that is dependent on the load (for example on the impedance of a loudspeaker), with the power limiting of the load resulting as a consequence of the voltage limiting of the audio signal 154.

[0017] The power amplifier 103 has a supply connection 144 which can be coupled to a power supply unit 102 in order to supply power to the power amplifier 103. The power supply unit 102 is optionally part of the audio amplifier 100, but it may also be accommodated outside the audio amplifier 100, so that the supply connection 144 is routed out of the audio amplifier 100 in order to allow the connection of an external power supply unit. The power supply unit 102 may therefore be an assembly of the audio amplifier 100 in the first case, and it may be a standalone appliance outside the audio amplifier 100 in the second case. The power supply unit 102 is used to supply power to the audio amplifier 100. For this purpose, the power supply unit 102 can be connected to a power source, for example to the 220V or 110V AC mains or to a private power supply system. The audio amplifier 100 is usually designed such that it requires a different power supply from that provided by the mains. The voltage conversion and the matching to the requirements of the audio amplifier 100 are brought about by the power supply unit 102. The output voltage and the maximum output current from the power supply unit 102 may be permanently set or variable. The power supply
unit 102 may be a switched-mode power supply unit or a transformer power supply unit. In the case of the former, the power supply unit may be of regulated or unregulated design.

[0018] The output 146 of the power amplifier can be coupled to a load 122, as a result of which the load 122 can be operated with the level-limited audio signal 154 at limited power. Between the output 146 of the power amplifier 103 and the load 122, there may also be further units, for example power output stages or filter units, in the signal path.

[0019] The audio amplifier 100 may have a housing 124 which accommodates the signal limiting circuit 101 and the power amplifier 103. It may also accommodate an optionally present digital-to-analogue converter 108 and an optionally present (internal) power supply unit 102 and also further signal processing units, which are not shown further in Figure 1.

[0020] The audio amplifier 100 described here can also be designed using power supply units in which the output voltages do not fall under load. Furthermore, the tonal properties of the power reduction are no longer dependent on the actual physical power supply unit 102 used, but rather are now dependent only on the design of the load-dependent limiting in the signal limiting circuit 101. It is therefore possible to implement different tonal characteristics by choosing the appropriate model of load-dependent limiting in the signal limiting circuit 101. A desired tonal response can therefore easily be ported to other audio amplifiers 100. It is also a simple matter for the power supply unit 102 within an audio amplifier 100 to be replaced by another without having to accept tonal influences.

[0021] By way of example, the audio amplifier 100 can be used for audio signal amplification for powerful loudspeakers which are
used for public address in large rooms or open areas. Such loudspeakers can produce an acoustic power of over 50 watts, particularly over 100 watts, which, when a loudspeaker has an acoustic efficiency of no more than 5%, for example, corresponds to electrical powers of over 1000 watts, particularly over 2000 watts. The audio amplifier 100 can also be used for the audio signal amplification in the case of loudspeaker arrays with a multiplicity of individual loudspeakers, in which relatively high acoustic powers in the region of multiples of 50 watts or 100 watts arise. The audio signal to be amplified is in the audible AF range from approximately 20 Hz to 20 kHz and above.

[0022] Figure 2 shows a block diagram of an audio amplifier 200 based on an exemplary embodiment of the invention. The audio amplifier 200 has a DSP 201, a power amplifier 103, a power supply unit 102, two analogue-to-digital converters 104a and 104b, a further digital-to-analogue converter 108, a digital input receiver 107, a controller 105 and a user interface unit 106. The digital input receiver 107 is connected between an analogue audio source 132 and an input 140 of the DSP 201 in order to convert an analogue signal 130 from the analogue audio source 132 into digital format and to provide it for the DSP 201 at the input 140 thereof as a digital audio signal 120. The digital-to-analogue converter 108 is connected between an output 142 of the DSP 201 and an input 148 of the power amplifier 103 in order to make the limited audio signal 150 produced by the DSP 201 available to the power amplifier 103 in analogue form as an analogue signal 152. The power amplifier 103 has a supply connection 144 which is coupled to the power supply unit 102 to allow it to be supplied with the output voltage 156 from the power supply unit 102. The power supply unit 102 has a supply voltage input which is coupled to a supply voltage source 126.
[0023] The power supply unit 102 is part of the audio amplifier 200 and may be an assembly of the audio amplifier 200. The power supply unit 102 is used to supply power to the audio amplifier 200. For this purpose, the power supply unit 102 is coupled to the supply voltage source 126. By way of example, the supply voltage source may be the 220V or 110V AC mains or a private power supply system. The audio amplifier 200 is usually designed such that it requires a different power supply from that provided by the voltage supply source 126. The voltage conversion and the matching to the requirements of the audio amplifier 200 are brought about by the power supply unit 102. The output voltage and the maximum output current of the power supply unit 102 may be permanently set or variable. The power supply unit 102 may be a switched-mode power supply unit or a transformer power supply unit. In the case of the former, the power supply unit may be of regulated or unregulated design.

[0024] The power amplifier 103 has its output 146 coupled to a load 122 in order to drive the load with the level-limited audio signal 154. The analogue-to-digital converters 104a and 104b are connected between the output 146 of the power amplifier 103 and a respective control unit 148a and 148b of the DSP 201 in order to provide the DSP 201 with the level-limited audio signal 154 in digital form, wherein the analogue-to-digital converter 104a converts a current component and the analogue-to-digital converter 104b converts a voltage component of the level-limited audio signal 154 into digital form. The controller 105 is coupled to the DSP 201 via a configuration interface 160, is coupled to the power supply unit 102 via a control interface 162, is coupled to the user interface unit 106 via a user interface 164 and is coupled to the remote control unit 128 via a remote control interface 166.

[0025] In this exemplary embodiment, the signal limiting circuit 101 from Figure 1 is in the form of a digital signal processor (DSP)
201, and the power amplifier 103 corresponds to the power amplifier 103 from Figure 1. In this exemplary embodiment, the received audio signal 120 is a digital audio signal which is received at an input 140 of the DSP 201. The DSP 201 limits the digital audio signal 120 received at this input 140 and provides it as a limited digital audio signal 150 at an output 142. In this exemplary embodiment, the input 140 and the output 142 are shown as an input and an output of the DSP 201. In other exemplary embodiments, in which the signal limiting circuit 101 comprises not only the DSP 201 but also further circuit units, the input 140 and the output 142 may be inputs and outputs of the signal limiting circuit 101 which are coupled to inputs and outputs of the DSP 201 via the further circuit units. Even though the exemplary embodiment in Figure 2 relates to a DSP 201, the same explanations apply mutatis mutandis even when, instead of the DSP 201, a digital microcontroller or microprocessor is used or when the functionality described here for the DSP 201 is performed both by a DSP and by a microcontroller or microprocessor or further digital hardware.

[0026] The DSP 201 delivers a limited digital audio signal 150 at its output 142. The power amplifier 103 amplifies a signal 152 which is based on the limited digital audio signal 150. In this exemplary embodiment, the power amplifier 103 is an analogue component which receives an analogue signal 152 at an input 148. To convert the limited digital audio signal 150 into an analogue signal 152, a digital-to-analogue converter 108 is used which converts the limited digital audio signal 150 into the analogue signal 152, which means that it is based on the limited digital audio signal 150. The block 108, which is denoted as a digital-to-analogue converter, may also have still further circuit units, for example sampling rate converters, i.e. circuits for reducing and/or increasing the sampling rate of the limited digital audio signal 150, so as to set any desired sampling rate for the limited digital audio signal 150, and/or filter stages, which are either
implemented in the digital-to-analogue converter 108 or are connected downstream of the digital-to-analogue converter 108, in order to implement a particular frequency response for the analogue signal 152 based on the limited digital audio signal 150.

[0027] The power amplifier 103 has a supply connection 144 which can be coupled to a power supply unit 102 and to which a power supply unit 102 is connected. The power supply unit 102 may, but does not have to, be one in which the output voltage 156 falls under load. By way of example, it may be a power supply unit 102 which delivers as constant an output voltage 156 as possible, for example by virtue of internal control loops which operate such that a sufficiently constant output voltage 156 is provided at the voltage output. The power supply unit 102 has an input which is coupled to a supply voltage source 126 which delivers the supply voltage from which the power supply unit 102 produces the output voltage 156 and makes it available to the power amplifier 103 at the power supply input 144 thereof.

[0028] The input 140 of the digital signal processor 201 receives a digital audio signal 120 which is based on an audio signal 130 which is provided by an audio source 132. The audio source 132 may be a digital or analogue audio source which provides a digital audio signal 130 or an analogue audio signal 130. In the case of a digital audio source 132, the DSP 201 may have an upstream digital circuit unit 107 in the form of a digital input receiver (DIR) which, if necessary, performs sampling rate conversion for the digital audio signal 130 so as to produce a converted digital audio signal 120 which has a desired sampling rate so that it can be received by the input 140 of the DSP 201. If the digital audio signal 130 already has the desired properties, the digital input receiver 107 can also be omitted, which means that the digital audio signal 130 is received directly by the input 140 of the DSP 201.
[0029] In the case of an analogue audio source 132, the DSP 201 may have an upstream analogue-to-digital converter 107 and optionally further upstream circuit units, said analogue-to-digital converter converting the analogue audio signal 130 into a digital audio signal 120 which can be received by the input 140 of the DSP 201. By way of example, the optionally present further circuit units can perform prefiltering on the analogue audio signal 130, for example low-pass filtering, high-pass filtering or bandpass filtering, so that a filtered analogue audio signal 130 is supplied to the analogue-to-digital converter 107. If necessary, the output signal delivered by the analogue-to-digital converter 107 can be subjected to sampling rate conversion or further digital filtering operations before it is received at the input 140 of the DSP 201.

[0030] The audio amplifier 200 has an analogue-to-digital converter 104a which is arranged between the output 146 of the power amplifier 103 and a control input 148a of the DSP 201, and which makes the level-limited audio signal 154 produced by the power amplifier 103 at the output 146 thereof available to the DSP 201 in digital form. This is the level-limited audio signal 154, as present on the load 122. The DSP 201 therefore has the opportunity to produce its limited audio signal 150 in a manner dependent on the load, since coupling the output 146 of the power amplifier 103 to the load 122 will involve the level-limited audio signal 154 assuming a load-dependent value.

[0031] The level-limited audio signal 154 produced by the power amplifier 103 can be measured using its current component and/or using its voltage component. In the exemplary embodiment in Figure 2, both components (i.e. current and voltage) are measured, with the analogue-to-digital converter 104a converting a current component of the level-limited audio signal 154 into digital format and making it available to the DSP 201 at the control input 148a
thereof. A further analogue-to-digital converter 104b, which is arranged between the output 146 of the power amplifier 103 and a further control input 148b of the DSP 201, converts a voltage component of the level-limited audio signal 154 into digital format and makes it available to the DSP 201 at the further control input 148b thereof. Hence, the DSP 201 can determine the limited audio signal 150 depending on the power of the level-limited audio signal 154 and hence depending on the power on the load 122.

[0032] In other exemplary embodiments, the audio amplifier 200 has just one of the two analogue-to-digital converters 104a and 104b, as a result of which only one current component of the level-limited audio signal 154 is made available to the DSP 201, for example. Since a load-dependent value will be obtained for the current component of the level-limited audio signal 154 when the output 146 of the power amplifier 103 is coupled to the load 122, the DSP 201 is able to produce the limited audio signal 150 depending on the load in these exemplary embodiments too.

[0033] Alternatively, in exemplary embodiments with just one of the two analogue-to-digital converters 104a and 104b, it is also possible for the voltage component instead of the current component to be made available to the DSP 201. However, the load dependency of the voltage is only minimal and is determined primarily by the internal resistance of the amplifier and the losses on the lines, which means the changes in the load 122 become noticeable only slightly in the voltage. It is therefore preferable to deliver the current component to the DSP 201 in exemplary embodiments with just one of the A/D converters 104a and 104b.

[0034] In another exemplary embodiment, the audio amplifier 200 has neither of the two analogue-to-digital converters 104a and 104b. In such an exemplary embodiment, information about the load 122, for example impedance values for the load, and/or the power
amplifier 103 is made available to the DSP 201, which information can be used in the DSP 201 to calculate how the limited audio signal 150 produced by the DSP 201 is converted into the level-limited audio signal 154 in order to drive the load. This information allows the DSP 201 to produce the limited audio signal 150 depending on the load.

[0035] The DSP 201 can produce the limited audio signal 150 on the basis of a model 310 of a power supply unit in which the output voltage falls under load. Such a model, as described in more detail in the subsequent exemplary embodiments in Figures 3 to 5, is used to produce the limited audio signal 150 depending on the load.

[0036] The audio amplifier 200 has a configuration interface 160 in order to transmit control and configuration data between a controller 105 or microprocessor and the DSP 201. The controller 105 is coupled to the power supply unit 102 via a control interface 162 in order to use control commands to set the power supply unit 102 and to request information from the power supply unit 102. The controller 105 is coupled to a user interface unit 106 via a user interface 164 in order to use control commands to configure the controller 105 and/or to load code into it and to request information from the controller 105. The controller 105 is coupled to a remote control unit 128 via a remote control interface 166 in order to use control commands to configure the controller 105 by remote control and/or to load code into it and to request information from the controller 105 by remote control.

[0037] The DSP 201 and the controller 105 may be produced as one circuit, which then corresponds to the signal limiting circuit 101 from Figure 1. The functionality of the DSP 201 can be performed fully or in part by the controller 105. Similarly, the functionality of the controller 105 can be performed fully or in part by the DSP 201.
[0038] The audio amplifier 200 has a housing 124 which accommodates the DSP 201, the power amplifier 103 and the power supply unit 102 and also the analogue-to-digital converters 104a and 104b, the digital-to-analogue converter 108, the digital input receiver 107, the controller 105 and the user interface unit 106.

[0039] The audio amplifier 200 can be used for the audio signal amplification for powerful loudspeakers that are used for public address in large rooms or open areas. Loudspeakers of this kind produce an acoustic power of over 50 watts, particularly over 100 watts. The audio amplifier 200 can also be used for the audio signal amplification in the case of loudspeaker arrays with a multiplicity of individual loudspeakers arranged above one another, in which relatively high acoustic powers in the region of multiples of 50 watts arise. The audio signal to be amplified is in the audible or just inaudible AF range from approximately 20 Hz to 20 kHz and above.

[0040] Figure 3 shows a block diagram of a digital signal processor 201 in an audio amplifier 200 based on an exemplary embodiment of the invention. The DSP 201 corresponds to the DSP 201 described in Figure 2. The DSP 201 has a signal path between the input 140 and the output 142, into which signal path a first audio processing unit 314, a peak value limiting unit 315 and a second audio processing unit 316 have been connected. The input 140 corresponds to the input 140 shown in Figure 2 for the DSP 201, at which the digital audio signal 120 is received. The output 142 corresponds to the output 142 shown in Figure 2, at which the limited digital audio signal 150 is provided.

[0041] The DSP 201 also has a control path between two control inputs 148a and 148b of the DSP 201 and the peak value limiting unit 315, which control path is used to actuate the peak value
limiting unit 315 with a controlled variable 326. The two control inputs 148a and 148b correspond to the control inputs 148a and 148b described in Figure 2 for the DSP 201. The control path has had a multiplication unit 312, a modelling unit 310 and a control unit 311 connected into it, wherein the modelling unit 310 obtains its input parameters for modelling a power supply unit in which the output voltage \( U_c \) falls under load from a parameter memory 313 and from the multiplication unit 312. The parameter memory 313 uses a parameter interface to provide the modelling unit 310 with a first parameter \( C \), which corresponds to a virtual capacitance, and with a second parameter \( P_{in} \), which corresponds to a prescribable maximum input power for the power amplifier 103. The multiplication unit 312 provides the modelling unit 310 with a third variable (directly controlled variable) \( P_{out} \) which is variable in operation and which corresponds to an output power of the power amplifier 103. The multiplication unit 312 comprises two inputs which correspond to the control inputs 148a and 148b of the DSP 201 and at which the multiplication unit 312 receives a current component \( I \) and a voltage component \( V \) of the level-limited audio signal 154 produced by the power amplifier 103 in digital form. From the voltage component \( U \) and the current component \( I \), the multiplication unit 312 forms the product, which emulates a power \( P_{out} \) of the level-limited audio signal 154 produced by the power amplifier 103. Optionally, the multiplication unit 312 comprises an integrator or a summator or an averaging unit, which it can use to make an averaged power \( P_{out} \) available to the modelling unit 310.

[0042] The parameter memory 313 is externally accessible via an external configuration interface 160 which can be used to set and/or request the parameters \( C \) and \( P_{in} \) stored in the parameter memory 313. The parameter memory 313 may be an internal memory in the DSP 201, as shown in Figure 3. Alternatively, the parameter memory 313 may be an external memory which the DSP 201 accesses via an external memory interface. In that case, the parameter
memory 313 would be implemented outside the DSP 201, contrary to the illustration in Figure 3.

[0043] The modelling unit 310 emulates a model of a power supply unit in which the output voltage $U_c$ falls under load. The model comprises a virtual capacitance $C$ which is charged with the supplied power $P_{in}$ and is discharged with the drawn power $P_{out}$. When the output of the virtual capacitance $C$ is connected to a load, the virtual capacitance $C$ discharges, with a load-dependent discharge current flowing and at the same time the output voltage $U_c$ across the virtual capacitance $C$ dipping. The output voltage $U_c$ falls under load. If the supplied power $P_{in}$ corresponds to the output power $P_{out}$, a power equilibrium establishes itself on the virtual capacitance $C$ and the virtual capacitance remains in the charged state. If the supplied power $P_{in}$ is higher than the output power $P_{out}$, the virtual capacitance is charged.

[0044] The model of the virtual capacitance is suitable for implementing power limiting control. So long as the drawn power $P_{out}$ is less than the suppliable power $P_{in}$, the output voltage $U_c$ assumes its maximum value $U_0$.

[0045] The virtual capacitance $C$ tolerates briefly occurring high power peaks in the drawn power $P_{out}$, which bring about partial discharge of the virtual capacitance $C$. In the case of high RMS powers in the drawn power, on the other hand, the virtual capacitance is discharged to a high degree.

[0046] In the first case, the output voltage $U_c$ falls only slightly below its maximum value, whereas in the second case, the output voltage $U_c$ quickly falls to low values.

[0047] Depending on the desired output power $P_{out}$, the supplied power $P_{in}$ can be set such that a power equilibrium is produced on
the virtual capacitance C. This makes it possible to implement a setting in which brief power peaks are transmitted whereas high RMS power values are limited.

[0048] The supplied power \( P_{\text{in}} \) is a constant parameter and does not change in the course of operation. \( U_3 \) is an upper limit for the supppliable power.

[0049] Such power limiting control is implemented in the modelling unit 310, wherein the supplied power \( P_{\text{in}} \) corresponds to a prescribed parameter which specifies the maximum input power on the virtual capacitance C, and the output power \( P_{\text{out}} \) denotes the power which is actually drawn for the load 122, which the multiplication unit 312 has calculated on the basis of the level-limited audio signal 154 applied to the load 122.

[0050] On the basis of the output voltage \( U_c \), the control unit 311 determines a controlled variable 326 which is used to actuate the peak value limiting unit 315. The peak value limiting unit 315 is used to limit the power peaks in the digital audio signal 120 applied to the input 140 by using the controlled variable 326. Specifically, the digital audio signal 120 enters the first audio processing unit 314, in which it is subjected to digital filtering and/or to routing in order to be received as a filtered digital audio signal 322 by the peak value limiting unit 315. In the peak value limiting unit 315, the filtered digital audio signal 322 is limited on the basis of the controlled variable 326 from the control unit 311, said limiting being brought about by reducing the signal level of the digital audio signal 322. The limited filtered digital audio signal 324 produced in this manner enters the second audio processing unit 316, in which it is subjected to further digital filtering and/or further limiting and is provided at the output 142 of the DSP 201 as a limited digital audio signal 150. The further limiting may be limiting which is independent of load, for example
limiting which matches the limited digital audio signal 150 to a subsequent digital-to-analogue converter 108.

[0051] In a further exemplary embodiment, the DSP 201 has no audio processing units 314 and 316. In that case, the signal 120 corresponds to the signal 322 and the signal 324 corresponds to the signal 150. In a further exemplary embodiment, the DSP 201 has no first audio processing unit 314. In that case, the signal 120 corresponds to the signal 322. In a further exemplary embodiment, the DSP 201 has no second audio processing unit 316. In that case, the signal 324 corresponds to the signal 150.

[0052] Figure 4 shows a block diagram of a digital signal processor 201 in an audio amplifier 200 based on an exemplary embodiment of the invention. The DSP 201 corresponds to the DSP 201 described in Figure 2 or to the DSP 201 described in Figure 3.

[0053] For the model of a power supply unit in which the output voltage $U_c$ falls under load, which power supply unit is emulated in the modelling unit 310, the relationship described below applies. Between the energy $W_c$ stored in the virtual capacitance $C$ and the voltage $U_c$ across the virtual capacitance $C$, the following relationship applies:

$$W_c = \frac{1}{2} \cdot C \cdot U_c^2.$$

[0054] On the other hand, there is a differential relationship between energy and power. Thus, power is the time derivation of energy and energy is power integrated with respect to time:

$$W_c = \int (P_{in} - P_{out}) \, dt.$$

[0055] Hence, the right-hand sides of both equations correspond, and the following relationship applies:
\[ U_C = f(P_{out}, P_{in}, C). \]

[0056] Figure 5 shows a block diagram of a digital signal processor 201 in an audio amplifier 200 based on an exemplary embodiment of the invention. The DSP 201 corresponds to the DSP 201 described in Figure 2 or to the DSP 201 described in Figure 3 and Figure 4.

[0057] For the model of a power supply unit in which the output voltage \( U_C \) falls under load, which power supply unit is emulated in the modelling unit 310, the relationship described below applies. Between the energy \( W_C \) stored in the virtual capacitance \( C \) and the voltage \( U_C \) across the virtual capacitance \( C \), the following relationship applies:

\[ W_C = \frac{1}{2} \cdot C \cdot U_C^2. \]

[0058] On the other hand, there is a differential relationship between energy and power. Thus, power is the time derivation of energy and energy is power integrated with respect to time:

\[ W_C = \int (P_{in} - P_{out}) \, dt. \]

[0059] If \( P_{in} \) and \( C \) are assumed to be constant, it is possible to calculate the voltage value \( U_C \) by observing the drawn power \( P_{out} \):

\[ \frac{1}{2} \cdot C \cdot \Delta U^2 = \int (P_{in} - P_{out}) \, dt \]

and from that:

\[ \Delta U^2 = \frac{2}{C} \cdot \int (P_{in} - P_{out}) \, dt. \]
[0060] Bearing in mind an initial condition for \(U_c\), \(U_c(0) = U_0 = \text{constant}\), the following is obtained:

\[
U_c^2 = U_0^2 + \Delta U^2
\]

and hence:

\[
U_c = \sqrt{(U_0^2 + \Delta U^2)}.
\]

[0061] The initial condition for \(U_c\), \(U_c(0) = U_3\) is stored in the parameter memory 313 as a prescribable parameter which is supplied to the modelling unit 310 via the parameter interface.

[0062] Figure 6 shows a schematic illustration to explain a method for amplifying an audio signal 120 based on an exemplary embodiment of the invention. The method has the steps indicated below. In a first step 601, an audio signal 120 is limited in order to produce a limited audio signal (150). In a second step 603, a signal 152 based on the limited audio signal 150 is amplified in order to produce a level-limited audio signal 154. In a third step 605, the level-limited audio signal 154 is provided at an output 146 which can be coupled to a load 122, as a result of which the load 122 can be operated at limited power because it is subject to level limiting. In this case, the limiting 601 takes place such that the limited audio signal 150 is limited depending on the load.
PATENT CLAIMS

1. Audio amplifier (100, 200), comprising:
   - a signal limiting circuit (101) which is configured to limit an audio signal (120) received at an input (140) and to provide it as a limited audio signal (150) at an output (142);
   - a power amplifier (103) which has a supply connection (144) configured to be coupled to a power supply unit (102) to supply power to the power amplifier (103), wherein the power amplifier (103) is configured to amplify a signal (152) based on the limited audio signal (150) and to provide it as a level-limited audio signal (154) at an output (146) thereof which is configured to be coupled to a load (122), so that the load (122) can be operated at limited power,
   - wherein the signal limiting circuit (101) is configured to produce an audio signal (150) which is limited depending on the load.

2. Audio amplifier (100, 200) according to Claim 1, in which the load (122) is a loudspeaker or a loudspeaker array.

3. Audio amplifier (100, 200) according to Claim 1 or 2, in which the signal limiting circuit (101) comprises a digital signal processor (201) and/or a microcontroller.

4. Audio amplifier (100, 200) according to one of the preceding claims, in which the signal limiting circuit (101) produces the audio signal (150) which is limited depending on the load on the basis of a model (310) of a power supply unit in which the output voltage ($U_c$) falls under load.

5. Audio amplifier (100, 200) according to one of the preceding claims, in which the signal limiting circuit (101) is configured to produce the limited audio signal (150) depending on the
level-limited audio signal (154) provided at the output (146) of the power amplifier (103).

6. Audio amplifier (100, 200) according to one of the preceding claims, further comprising:
a digital-to-analogue converter (108) which is arranged in a signal path between the signal limiting circuit (101) and the power amplifier (103).

7. Audio amplifier (100, 200) according to one of the preceding claims, further comprising:
a power supply unit (102) which is coupled to the supply connection (144) of the power amplifier (103), wherein the power supply unit (102) is configured to produce a load-independent output voltage (156).

8. Audio amplifier (100, 200) according to one of the preceding claims, further comprising:
an analogue-to-digital converter (104a) which is arranged between the output (146) of the power amplifier (103) and a control input (148a) of the signal limiting circuit (101), wherein the analogue-to-digital converter (104a) provides a current component (I) of the level-limited audio signal (154) for the signal limiting circuit (101).

9. Audio amplifier (100, 200) according to Claim 8, further comprising:
a further analogue-to-digital converter (104b) which is arranged between the output (146) of the power amplifier (103) and a further control input (148b) of the signal limiting circuit (101), wherein the further analogue-to-digital converter (104b) provides a voltage component (V) of the level-limited audio signal (154) for the signal limiting circuit (101).
10. Audio amplifier (100, 200) according to one of the preceding claims, wherein the signal limiting circuit (101) is configured to determine the audio signal (150) which is limited depending on the load on the basis of a function of a prescribable maximum input power \( (P_{in}) \) of the power amplifier (103), an output power \( (P_{out}) \) of the power amplifier (103) and a virtual capacitance \( (C) \).

11. Audio amplifier (100, 200) according to Claim 10, wherein the signal limiting circuit (101) is configured to determine the output power \( (P_{out}) \) of the power amplifier (103) on the basis of a product of the current component \( (I) \) and the voltage component \( (V) \) of the level-limited audio signal (154).

12. Audio amplifier (100, 200) according to Claim 10, further comprising:
   a configuration interface (160) configured to adjust the virtual capacitance \( (C) \) and the prescribable maximum input power \( (P_{in}) \) of the power amplifier (103).

13. Method for amplifying an audio signal (120), comprising:
   limiting (601) the audio signal (120) in order to produce a limited audio signal (150);
   amplifying (603) a signal (152) which is based on the limited audio signal (150) in order to produce a level-limited audio signal (154); and
   providing (605) the level-limited audio signal (154) at an output (146) which is configured to be coupled to a load (122), so that the load (122) can be operated at limited power,
   wherein the limiting (601) is effected such that the limited audio signal (150) is limited depending on the load.

14. Method according to Claim 13, wherein the load (122) is a loudspeaker or a loudspeaker array.
15. Method according to Claim 13 or 14, wherein the limiting (601) is effected on the basis of a model (310) of a power supply unit in which the output voltage \((U_c)\) falls under load.

16. Method according to Claim 15, wherein the limiting (601) is effected using the following formulae:

\[
U_c = \sqrt{(U_0^2 + \Delta U^2)},
\]

\[
\Delta U^2 = \frac{2}{C} \cdot \int (P_{in} - P_{out}) \, dt,
\]

where \(P_{in}\) is a maximum prescribable input power on a virtual capacitance \(C\), \(P_{out}\) is an output power on the virtual capacitance \(C\), \(\Delta U\) is a differential voltage change on the virtual capacitance \(C\), \(U_0\) is an initial voltage on the virtual capacitance \(C\), and \(U_c\) is the output voltage of the model (310) of a power supply unit in which the output voltage \((U_c)\) falls under load.

17. Method according to Claim 15 or 16, wherein the output voltage \((U_c)\) is taken as a basis for altering a threshold which is used to limit peak values of the audio signal (120).

18. An audio amplifier as substantially herein described with reference to the accompanying Figures.
**Patents Act 1977: Search Report under Section 17**

### Documents considered to be relevant:

<table>
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<th>Category</th>
<th>Relevant to claims</th>
<th>Identity of document and passage or figure of particular relevance</th>
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<tr>
<td>X,P</td>
<td>1-3, 5, 6, 8, 13 &amp; 14</td>
<td>US 2012/002819 A1 (Thormundson et al.) See e.g. fig. 6</td>
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<td>X</td>
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<td>US 2009/257599 A1 (BANG &amp; OLUFSEN ICEPOWER AS) See e.g. par. 11, 18 &amp; 31-33, and fig. 1</td>
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<tr>
<td>X</td>
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<td>WO 2008/143124 A1 (TOA Corp) See e.g. fig. 1</td>
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<td>US 2008/056504 A1 (Gorges, F. &amp; Edcler, W.) See e.g. par 28, 45, 57, 73, 88 &amp; 93 and figs. 2 &amp; 3</td>
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<td>X</td>
<td>1-3, 5, 6, 8, 9, 13 &amp; 14</td>
<td>US 2004/178852 A1 (QSC AUDIO PROD INC [US]) See e.g. figs. 2, 3, 5 &amp; 6</td>
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**Field of Search:**

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC:

- H03G

Worldwide search of patent documents classified in the following areas of the IPC

- **H03G**

The following online and other databases have been used in the preparation of this search report:

- Online databases: EPODOC, WPI
### International Classification:

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