

PATENT SPECIFICATION

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(54) IMPROVEMENTS IN AUDIO AMPLIFIERS

(71) We, HITACHI LIMITED of 1-5-1 Marunouchi, Chiyoda-ku, Tokyo, Japan, a body corporate organized according to the laws of Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to audio amplifiers, and more particularly to an audio amplifier which is constructed so as to prevent a transient noise known as the "pop noise" arising at switch-on.

In the field of audio amplifiers, the pop noise which may be generated when a power source is turned on, is a problem. Pop noise is generated by an excessive current flowing through a speaker being the load of the amplifier at switch on and it is possible that the speaker will be damaged by this excessive impulsive current.

An object of the present invention is to provide an audio amplifier wherein substantially no pop noise arises at switch on.

Another object of the present invention is to provide an audio amplifier whereof the pop noise preventing means is constructed so as not to influence operation of the amplifier circuit under the steady state conditions.

According to the present invention there is provided an audio amplifier including: an output amplifier circuit; means for connecting said amplifier to a power source; a power switch for supplying electric power from said connecting means to said amplifier circuit; and a starter circuit operating in synchronism with the power switch, for starting the operation of said amplifier circuit, said starter circuit having means for setting the electric potential of a signal path for low-frequency signals at a predetermined value when said power switch is closed so as to set the output potential of said output amplifier circuit substantially at zero potential, and which subsequently gradually raises the

output potential of said output amplifier circuit from zero to a predetermined operating voltage; said starter circuit including a device which is conductive at starting but is automatically rendered non-conductive when said amplifier reaches a steady state.

The present invention will now be described in greater detail by way of example with reference to the accompanying drawings, wherein:—

Figure 1 is a circuit diagram of a first embodiment of an audio amplifier according to the present invention;

Figures 2a to 2d are waveform diagrams for the audio amplifier circuit of Figure 1, Figures 2a and 2b showing changes of a mid-point potential VQ of a push-pull output amplifier circuit and a transient current flowing through an output terminal OUT, respectively plotted to a base of time, these being the waveforms relating to the circuit in the absence of a starting circuit ST, whilst Figures 2c and 2d show changes of the base potentials (VB)Q1 and (VB)Q2 of a pair of input transistors comprising a differential amplifier and the mid-point potential VQ in the presence of a starting switch ST, respectively, both plotted to a base of time; and

Figures 3 and 4 are circuit diagrams of second and third embodiments of the present invention.

Figures 5a and 5b are waveform diagrams showing changes of the base potential (VB)Q41 and (VB)Q42 of a pair of input transistors and the mid-point potential VQ both plotted to a base of time.

The first embodiment of the present invention is shown in Figure 1 and comprises an audio power amplifier whereof a group of transistors Q1 to Q3 are the active elements of a differential amplifier. The transistor Q3 functions as a constant-current source. To the base electrodes of the transistors Q1 and Q2 are applied respectively a low-frequency input signal and a feedback signal. A capacitor C1, which is connected between an input

terminal IN and the base electrode of the transistor Q1 couples the amplifier to an input signal. A capacitor C2 attenuates the A.C. component of a supply voltage.

5 Transistors Q4 and Q5 are part of a level shift circuit, and function to reduce the D.C. level of the output voltage of the differential amplifier.

10 Transistors Q6 and Q7 comprise a driver circuit which drives a push-pull circuit in the succeeding stage.

15 Transistors Q8—Q11 comprise a class-B push-pull amplifier circuit. An output voltage VQ of the amplifier circuit is fed through a capacitor C6 to an output terminal OUT, and is also fed back through resistors R8 and R12 and a capacitor C3 to the differential amplifier at the second input of the amplifier.

20 The feedback circuit provides temperature compensation for the amplifier and reduces its distortion factor.

25 A capacitor C4 provides phase correction whilst a capacitor C7 applies further stabilization. A capacitor C5 bootstraps the driver stage.

30 A starting circuit generally designated ST and comprising transistors Q12 and Q13 and resistors R13 and R14 is provided in order to prevent the aforementioned pop noise.

35 The base electrodes of the transistors Q12 and Q13 are connected to the junction between resistors R2 and R3, whilst their emitter electrodes are connected via the resistor R14 to a voltage source VCC. The resistor R13 is connected between the emitter electrodes of the transistors Q12 and Q13 and earth. The emitter electrodes of the transistors Q12 and Q13 are biased with a voltage which is produced by the potential division of the supply voltage VCC by the resistors R13 and R14. The collector electrode of the transistor Q12 is connected to the capacitor C3, whilst the collector electrode of the transistor Q13 is connected to the base electrode of the transistor Q6 of the driver circuit.

40 Before explaining the operation of the audio amplifier shown in Figure 1, the process by which the pop noise is generated will be described in connection with a power amplifier circuit without the starting circuit ST.

55 In the absence of the starting circuit ST;

1. When a power switch SW is turned on, the terminal voltage of the capacitor C2 is zero, and hence, the transistors Q1 and Q2 are non-conductive. In consequence, the transistors Q4 and Q6—Q9 are also non-conductive. Since the time constant of resistor R10 and the capacitor C5 is small, the output potential VQ of the push-pull circuit (the mid-point potential) instantly rises from its initial level (the electric

potential which the circuit has before the closure of the power switch SW) to the supply voltage VCC.

2. When the mid-point potential VQ becomes equal to the supply voltage VCC, the capacitor C3 is charged through the resistor R8. The base potential of the transistor Q2 is thereby made higher than that of the transistor Q1, so that the transistor Q2 is rendered conductive. As a result, the transistors Q4 and Q6—Q9 are rendered conductive, and the mid-point potential VQ becomes substantially equal to that of earth (its initial potential).

3. When the mid-point potential VQ becomes equal to earth potential, charges stored in the capacitor C3 are discharged through the resistor R8. The base potential of the transistor Q2 falls below that of the transistor Q1. The mid-point potential VQ leaps up to the supply voltage VCC again.

4. Subsequently, the capacitor C3 is charged again. Finally, the base potentials of the transistors Q1 and Q2 reach an equilibrium point. The mid-point potential VQ is set at a predetermined value (for example, $1/2$ VCC).

In the foregoing manner, in the absence of the starting circuit ST, the mid-point potential VQ changes between earth potential and the supply voltage as is illustrated in Figure 2a. A transient current flows to the output terminal OUT as shown in Figure 2b resulting from differentiation of the mid-point voltage VQ by the coupling capacitor C6. The pop noise is generated by this output current.

The embodiment of Figure 1 includes the starting circuit ST, in order to prevent a large transient current from flowing to the load at switch-on. The starting circuit ST operates so as to set the mid-point potential VQ at approximately earth potential at the instant of switch-on of the power supply, and thereafter to raise the mid-point potential VQ gradually from the earth potential to, for example, a potential of a half of the supply voltage VCC. When the mid-point potential VQ becomes equal to $1/2$ VCC, the starting circuit ST is isolated from the audio signal path. Description will now be made of the operation of the starting circuit.

In the presence of the starting circuit ST:

1. At the instant of switch-on of the power switch SW, the terminal voltage of the capacitor C2 is zero, so the base potentials of the transistors Q12 and Q13 are also zero. Simultaneously therewith, the base-emitter junctions of the transistors Q12 and Q13 are forward biased, to render the transistors conductive. Upon conduction of the transistor Q13, the transistors Q6 and Q7 are also rendered conductive (saturated). The potential VQ is

first set, as illustrated in Figure 2d, at zero volts (strictly, at $2 V_{BE_{sat}}$ where $V_{BE_{sat}}$ denotes a base-emitter voltage drop in the saturated region).

2. Since the transistor Q12 is conductive, the capacitor C3 is charged through the transistor Q12, and the capacitor C2 is also gradually charged through a resistor R1. As the capacitor C2 is gradually charged, the base potentials of the transistors Q12 and Q13 are increased. Before long, the transistors Q12 and Q13 are reverse-biased and rendered non-conductive (at time t_1). At this time the transistor Q2 is rendered conductive (saturated), since the capacitor C3 has been charged as the transistor Q12 was previously rendered conductive so that, as illustrated in Figure 2c, the base potential (VB)Q2 of the transistor Q2 may become higher than the base potential (VB)Q1 of the transistor Q1. When the transistor Q2 conducts, the transistor Q4 is rendered conductive, and therefore, the transistors Q6 and Q7 continue to operate in the saturated region.

3. Subsequently, since the mid-point potential VQ is substantially zero, the charge stored in the capacitor C3 is discharged through the feedback resistor R8, and the base potential (VB)Q2 begins to fall. On the other hand, the base potential (VB)Q1 is still rising. The difference between the base potentials becomes small. In due course, the differential amplifier begins to operate in a linear region (within its dynamic range) of its transmission characteristic (at a time t_2). As shown in Figure 2d, the mid-point potential VQ rises gradually.

As the mid-point potential VQ rises, discharge of the capacitor C3 becomes slow. When the mid-point potential VQ exceeds the base potential (VB)Q2, the capacitor C3 begins to be, contrariwise, charged again, allowing the base potentials (VB)Q1 and (VB)Q2 to rise substantially together. Finally the differential amplifier is balanced, and the mid-point potential VQ is fixed at $1/2 V_{CC}$.

It is required that, when the transistor Q13 is cut off, the base potential (VB)Q2 rises above the base potential (VB)Q1. To this end, it is required that the charging time constant of the capacitor C2 is made larger than the charging time constant of the capacitor C3. Although various elements contribute to the time constants, the aforesaid requirement is fulfilled by, for example, making the resistance of the resistor R1 in the bias circuit sufficiently high and making the capacity of the capacitor C2 sufficiently large. Even if the time constants of the bias circuit as altered in this manner the frequency characteristics of the audio amplifier are not affected.

As described above, the mid-point potential VQ is first set at earth potential and then it gradually rises to the voltage of $1/2 V_{CC}$ as illustrated in Figure 2d. Therefore, no large transient current flows through the load and the pop noise is prevented.

In the steady state condition reached a short time after switch-on, the transistors Q12 and Q13 are automatically cut off. The time constant circuit (C2, R1) of the starting circuit ST is then isolated from the audio signal path at, for example, the base electrodes of the transistors Q2 and Q6. Hence, the capacitor C2 and the resistor R1 need not be considered when designing the signal path of the amplifier. Accordingly, the circuit design is subject to no additional restriction on account of the starting circuit. Low-frequency signals are not influenced by the capacitor C2 and resistor R1, so design of the signal paths can be made without considering these elements.

The starting circuit ST functions only during the period of transition after switch-on and is independent of the amplifier circuit under steady state conditions.

In order to render the non-linear elements, such as transistors Q12 and Q13, conductive transiently and non-conductive under steady state conditions, time constant circuits are required. Capacitors C2 and C3, which are used as components for the ripple filter and the feedback circuit under the steady state conditions of the amplifier circuit, respectively, are also utilized as components for the time constant circuit of the starting circuit ST in the present embodiment. It is thus unnecessary to provide additional capacitors for the starting circuit. It is the tendency now that the circuit of the audio amplifier is made in the form of an integrated semiconductor circuit as are digital circuits. From the viewpoint of area required, however, it is difficult to make a large capacitor in a monolithic semiconductor substrate. It is therefore necessary to mount capacitors individually outside the substrate. Hence, an increase in the number of capacitors increases, not only the number of components, but also the number of external terminals required for the integrated semiconductor circuit.

It should be further noted that the period ($t_2 - t_0$) during which the midpoint potential VQ is held substantially at zero volts can be lengthened by increasing the time constant based on the capacitor C2 and the resistor R1. The signal from a pre-amplifier driving the power amplifier circuit, can thus be cut off from the speaker which is the power amplifier load during that period.

In particular, even if a pop noise signal is

generated in the pre-amplifier circuit, the pop noise will not reach the speaker since the power amplifier circuit does not operate during the period from the time t_0 to the time t_2 . Thus, it is not necessary to provide separate, pop noise-preventing means for the pre-amplifier circuit.

A second embodiment of an audio amplifier according to the present invention is shown in Figure 3.

Referring to Figure 3, a diode D23 is connected between a capacitor C22 (the ripple filter capacitor and a capacitor C23 which blocks the D.C. level.

The cathode electrode of a diode D24 is connected to the base electrode of a transistor Q29 forming a class-A driver circuit, whilst the anode electrode of diode D24 is connected to the collector electrode of a transistor Q21.

The common emitter stage formed by transistor Q21 has its base electrode earthed through resistors R23 and R22, and has its collector electrode connected to a voltage source VCC through a resistor R26 and diodes D21 and D22.

The operation of an audio amplifier provided with such a starter circuit ST will now be explained.

1. At the instant of switch-on, the terminal voltage of the capacitor C22 is zero, and hence, the transistor Q21 is non-conductive. Base currents will flow in the transistor Q29 and a transistor Q30 via the diodes D21, D22 and D24 and the resistor R26, to render the transistors Q29 and Q30 conductive. The mid-point potential VQ is set at approximately zero volts.

Simultaneously therewith, the base potential of a transistor Q27 is held at approximately zero volts since the resistance of a resistor R28 is sufficiently small in comparison with that of a resistor R30. The diode D23 is consequently forward-biased, and rendered conductive.

2. As the capacitor C22 is gradually charged, the base potential of the transistor Q21 rises. Therefore, the transistor Q21 is rendered conductive. Due to the conduction of the transistor Q21, the anode potential of the diode D24 is reduced to substantially earth potential, and the diode D24 is rendered non-conductive.

At this instant, the base potential of the transistor Q27 has become higher than that of a transistor Q24, since the capacitor C23 has been charged by the previous conduction of the diode D23. As has been explained in connection with the embodiment of Figure 1, the mid-point potential VQ continues to be substantially zero volts.

3. Thereafter, as in the case of the embodiment shown in Figure 1, the difference between the base potentials of

the transistors Q24 and Q27 gradually diminishes. As a result, the mid-point potential VQ begins to rise gradually from approximately zero to $1/2$ VCC. Finally, the differential amplifier is balanced to set the mid-point potential VQ to $1/2$ VCC.

Under steady state conditions, the differential amplifier is balanced, and the base potentials of its transistors Q24 and Q27 are substantially equal. Therefore, the diode D23 is reverse-biased by an amount corresponding to the voltage drop of a resistor R21, and is non-conductive.

In some differential amplifiers, the diode D23 is somewhat forward-biased under steady state conditions. This is not disadvantageous unless the threshold voltage of the diode (about 0.7 V for a silicon diode) is exceeded.

A third embodiment of the audio amplifier according to the present invention is shown in Figure 4.

Referring to Figure 4, the starting circuit ST is comprised of resistors R51 and R52 and a transistor Q49. The resistors R51 and R52 are connected in series between a voltage source VCC and earth. The transistor Q49 has its base electrode connected through the resistor R51 to the voltage source VCC, its collector electrode connected to the base electrode of a transistor Q43 for level shift, and its emitter electrode connected to a capacitor C43 to block D.C. signals.

The operation of the audio amplifier provided with such starting circuit ST will now be described.

1. At the instant of power switch-on, the base potential of a transistor Q42 becomes approximately zero to bias the transistor Q49 in the forward direction and to render it conductive, because the resistance of a resistor R50 is small in comparison with the resistance of resistor R47. Upon conduction of the transistor Q49, a base current flows in the transistor Q43, and the transistor Q43 is rendered conductive. Simultaneously therewith, a transistor Q44 is rendered conductive. The mid-point potential VQ is set at substantially zero volts.

On the other hand, whilst transistor Q49 is conductive, capacitor C43 is charged by the current flowing through transistor Q49. Assuming that the time constant of the circuit including the capacitor C43 is smaller than that of the circuit including the capacitor C42, the base voltage of transistor Q42 is kept higher than that of transistor Q41 as shown in Figure 5a. Accordingly, transistor Q42 is made conductive whilst transistor Q49 is conductive.

2. Thereafter, the transistor Q49 becomes non-conductive, if the resistances of the

resistor R51 and R52 are selected so as to satisfy the following condition:

$$R42/(R41+R42) > R52/(R51+R52) - VBE/VCC$$

where VBE denotes the threshold voltage of the transistor, and the voltage drop of a resistor R43 is neglected.

Since capacitor C43 is charged up to a voltage so that the base voltage of transistor Q42 is higher than that of transistor Q41, transistor Q42 is still kept conductive even after transistor Q49 is made non-conductive. Accordingly, transistor Q43 is kept conductive, and transistors Q44, Q45 and Q46 are conductive. The mid-point potential VQ therefore is substantially zero volts until t_2 as shown in Figure 5b.

Subsequent operation of the starting switch circuit of this embodiment is substantially the same as in the circuit of Figure 1.

Although in the above embodiments, a starting circuit ST according to the present invention is provided in the power amplifier circuit, such starting circuit may be provided in a pre-amplifier circuit which may be connected to the input IN of the power amplifier circuit shown in Figures 1, 3 and 4 in the same manner.

Although, in the foregoing embodiment of the power amplifier circuits, the input stage of the amplifier circuit has been described as being a differential amplifier, the present invention is similarly applicable to a power amplifier circuit in which a single stage of class-A amplifier circuit is used as the power amplifier input stage.

The transistor Q21 of the starting circuit in the audio amplifier of Figure 3 is held conductive under steady state conditions. In contrast, the corresponding transistors in the embodiments in Figures 1 and 4 are held non-conductive under steady state conditions, these embodiments being advantageous in this respect.

In all of the foregoing embodiments, the ripple filter employed for the amplifier circuit is also used as part of the circuit which raises the output potential of the output amplifier circuit from earth potential to the steady state potential, thus minimizing the number of components required by the circuit. However a separate time constant circuit can be connected to the input of the starting circuit. In this case, the principal object of the present invention, i.e. the elimination of the pop noise can be similarly accomplished.

Furthermore, it will be appreciated that in the above circuits, it is not necessary to add an additional capacitor for the purpose of preventing the pop noise.

WHAT WE CLAIM IS:—

1. An audio amplifier including: an output amplifier circuit; means for connecting said amplifier to a power source; a power switch for supplying electric power from said connecting means to said amplifier circuit; and a starter circuit operating in synchronism with the power switch for starting the operation of said amplifier circuit, said starter circuit having means for setting the electric potential of a signal path for low-frequency signals at a predetermined value when said power switch is closed so as to set the output potential of said output amplifier circuit substantially at zero potential, and which subsequently gradually raises the output potential of said output amplifier circuit from zero to a predetermined operating voltage; said starter circuit including a device which is conductive at starting but is automatically rendered non-conductive when said amplifier reaches a steady state.

2. An audio amplifier according to claim 1, wherein said starter circuit includes two transistors, the commoned emitter electrodes of which are biased at a voltage level being a fixed proportion of the supply voltage; and the commoned base electrodes of which are connected to a voltage which rises exponentially towards a fixed proportion of said supply voltage such that the said two transistors, on application of said supply voltage are initially saturated and subsequently cut off, the collector currents of said transistors controlling the starting voltage levels of the audio amplifier.

3. An audio amplifier according to claim 1, wherein said starter circuit includes a transistor and first and second diodes, the base electrode of said transistor being biased by a voltage which rises exponentially on the application of the power supply to the amplifier to a fixed proportion of said power supply voltage, the emitter electrode of said transistor being earthed and the collector electrode of said transistor biasing said first diode, said second diode being biased to conduct when said amplifier power supply is initially switched on and before said amplifier reaches a steady state, conduction of said diodes controlling the starting of the amplifier.

4. An audio amplifier according to claim 1, wherein said starter circuit includes a transistor, the base electrode of which is biased to a suitable proportion of power supply voltage such that said transistor conducts transiently on application of the supply voltage, the collector and emitter electrodes of said transistor controlling the starting of the amplifier.



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resistor R51 and R52 are selected so as to satisfy the following condition:

$$R42/(R41+R42) >$$

$$R52/(R51+R52) - VBE/VCC$$

5 where VBE denotes the threshold voltage of the transistor, and the voltage drop of a resistor R43 is neglected.

10 Since capacitor C43 is charged up to a voltage so that the base voltage of transistor Q42 is higher than that of transistor Q41, transistor Q42 is still kept conductive even after transistor Q49 is made non-conductive. Accordingly, transistor Q43 is kept conductive, and transistors Q44, Q45 and Q46 are conductive. The mid-point potential VQ therefore is substantially zero volts until t2 as shown in Figure 5b.

15 Subsequent operation of the starting switch circuit of this embodiment is substantially the same as in the circuit of Figure 1.

20 Although in the above embodiments, a starting circuit ST according to the present invention is provided in the power amplifier circuit, such starting circuit may be provided in a pre-amplifier circuit which may be connected to the input IN of the power amplifier circuit shown in Figures 1, 3 and 4 in the same manner.

25 Although, in the foregoing embodiment of the power amplifier circuits, the input stage of the amplifier circuit has been described as being a differential amplifier, the present invention is similarly applicable to a power amplifier circuit in which a single stage of class-A amplifier circuit is used as the power amplifier input stage.

30 The transistor Q21 of the starting circuit in the audio amplifier of Figure 3 is held conductive under steady state conditions. In contrast, the corresponding transistors in the embodiments in Figures 1 and 4 are held non-conductive under steady state conditions, these embodiments being advantageous in this respect.

35 In all of the foregoing embodiments, the ripple filter employed for the amplifier circuit is also used as part of the circuit which raises the output potential of the output amplifier circuit from earth potential to the steady state potential, thus minimizing the number of components required by the circuit. However a separate time constant circuit can be connected to the input of the starting circuit. In this case, the principal object of the present invention, i.e. the elimination of the pop noise can be similarly accomplished.

40 Furthermore, it will be appreciated that in the above circuits, it is not necessary to add an additional capacitor for the purpose of preventing the pop noise.

WHAT WE CLAIM IS:—

1. An audio amplifier including: an output amplifier circuit; means for connecting said amplifier to a power source; a power switch for supplying electric power from said connecting means to said amplifier circuit; and a starter circuit operating in synchronism with the power switch for starting the operation of said amplifier circuit, said starter circuit having means for setting the electric potential of a signal path for low-frequency signals at a predetermined value when said power switch is closed so as to set the output potential of said output amplifier circuit substantially at zero potential, and which subsequently gradually raises the output potential of said output amplifier circuit from zero to a predetermined operating voltage; said starter circuit including a device which is conductive at starting but is automatically rendered non-conductive when said amplifier reaches a steady state.

2. An audio amplifier according to claim 1, wherein said starter circuit includes two transistors, the commoned emitter electrodes of which are biased at a voltage level being a fixed proportion of the supply voltage; and the commoned base electrodes of which are connected to a voltage which rises exponentially towards a fixed proportion of said supply voltage such that the said two transistors, on application of said supply voltage are initially saturated and subsequently cut off, the collector currents of said transistors controlling the starting voltage levels of the audio amplifier.

3. An audio amplifier according to claim 1, wherein said starter circuit includes a transistor and first and second diodes, the base electrode of said transistor being biased by a voltage which rises exponentially on the application of the power supply to the amplifier to a fixed proportion of said power supply voltage, the emitter electrode of said transistor being earthed and the collector electrode of said transistor biasing said first diode, said second diode being biased to conduct when said amplifier power supply is initially switched on and before said amplifier reaches a steady state, conduction of said diodes controlling the starting of the amplifier.

4. An audio amplifier according to claim 1, wherein said starter circuit includes a transistor, the base electrode of which is biased to a suitable proportion of power supply voltage such that said transistor conducts transiently on application of the supply voltage, the collector and emitter electrodes of said transistor controlling the starting of the amplifier.

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5. An audio amplifier constructed and arranged to operate substantially as herein described with reference to and as illustrated in Figures 1 and 2, or Figure 3, or Figures 4 and 5 of the accompanying drawings.

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