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CLAMPING CIRCUIT AND OFFSET OTA CIRCUIT THEREOF

Abstract

A clamping circuit for clamping its voltage difference between its first and second terminals includes: an offset operational trans-conductance amplification (OTA) circuit for generating an output current according to a differential mode voltage between its first and second terminals which have a common mode offset voltage; and an amplifier circuit for generating a first terminal voltage according to the output current of the offset OTA circuit, so as to clamp the voltage difference of the clamping circuit to not exceeding a clamping voltage level. The offset OTA circuit includes a first and a second offset OTA sub-circuits, which have common mode offset voltages, and an auxiliary offset circuit. The common mode offset voltage of the offset OTA circuit is equal to a sum of the common mode offset voltages of the first and the second offset OTA sub-circuit and an offset voltage of the auxiliary offset circuit.

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Background/Summary

CROSS REFERENCE

[0001] The present invention claims priority to TW patent application No. 113106218, filed on Feb. 21, 2024.

BACKGROUND OF THE INVENTION

Field of Invention

[0002] The present invention relates to a clamping circuit, particularly to a clamping circuit capable of precise clamping. The invention also relates to an offset operational trans-conductance amplification (OTA) circuit used within the clamping circuit.

Description of Related Art

[0003] FIG. 1A and FIG. 1B show schematic diagrams of clamping circuits from prior art. In the clamping circuit 91A of prior art shown in FIG. 1A, the gate-source voltage V_{gs0} of the metal oxide semiconductor (MOS) transistor M0 is substantially clamped to twice the gate-source voltage V_{gs} of the diode-connected transistors M1 and M2, which are serially coupled, i.e., substantially clamped to twice the conduction threshold voltage of the MOS transistor. In the clamping circuit 91B of prior art shown in FIG. 1B, the gate of the MOS transistor M3 is coupled to the drain of MOS transistor M4, and its source is coupled to the gate of MOS transistor M4, thereby substantially clamping the gate-source voltage V_{gs0} of the MOS transistor M0 to twice the gate-source voltage V_{gs} of the MOS transistor, i.e., substantially clamping to twice the conduction threshold voltage of the MOS transistor.

[0004] FIG. 1C shows the characteristic curve of clamping current and voltage for clamping circuits from prior art. As illustrated in FIG. 1C, when the gate-source voltage V_{gs0} (i.e., the clamping voltage V_{out}) of the MOS transistor M0 exceeds the clamping threshold voltage V_{cth} , the clamping circuit 91A or 91B start to operate, clamping the gate-source voltage V_{gs0} of the MOS transistor M0 at the clamping threshold voltage V_{cth} within a range limited by a maximum current I_{max} .

[0005] A drawback of the prior art, as shown in FIG. 1C, is that the clamping current I_{out} starts to increase before the clamping voltage V_{out} reaches the clamping threshold voltage V_{cth} , indicating that the prior art clamping circuits have leakage currents and poor gain, failing to achieve precise clamping (as indicated by the long dashed line in FIG. 1C).

[0006] Compared to the aforementioned prior art, the present invention provides a clamping circuit capable of precise clamping. Through the design of the offset operational trans-conductance amplification (OTA) circuit within the clamping circuit of the present invention, the characteristic curve of clamping current and voltage can be made to approach the ideal state, as indicated by the long dashed line in FIG. 1C, achieving precise clamping of the clamping circuit (e.g., the aforementioned MOS transistor M0). The clamping circuit of the present invention achieves advantages such as power saving, high efficiency, and high stability.

SUMMARY OF THE INVENTION

[0007] From one perspective, the present invention provides a clamping circuit for clamping a voltage difference between a first terminal and a second terminal of the clamping circuit so as not to exceed a clamping voltage level, comprising: an offset operational trans-conductance amplification (OTA) circuit configured to generate an output current at its output terminal according to a differential mode voltage between a first input terminal and a second input terminal, wherein a common mode offset voltage is present between the first input terminal and the second

input terminal thereof, wherein the first input terminal and the second input terminal of the offset OTA circuit are respectively coupled to the first terminal and the second terminal of the clamping circuit; and an amplification stage circuit coupled between the output terminal and the first input terminal of the offset OTA circuit, configured to generate a first terminal voltage at the first terminal of the clamping circuit according to the output current of the offset OTA circuit, so as to clamp the voltage difference of the clamping circuit to not exceed the clamping voltage level; wherein the clamping voltage level corresponds to the common mode offset voltage of the offset OTA circuit; wherein the offset OTA circuit includes: a first offset OTA sub-circuit having a common mode offset voltage between its first input terminal and its second input terminal, configured to generate the output current of the offset OTA circuit at the output terminal of the offset OTA circuit based on a differential mode voltage between the first input terminal and the second input terminal thereof; a second offset OTA sub-circuit having a common mode offset voltage between its first input terminal and its second input terminal, configured to generate the output current of the offset OTA circuit at the output terminal of the offset OTA circuit based on a differential mode voltage between the first input terminal and the second input terminal thereof; and an auxiliary offset circuit configured to generate an auxiliary offset voltage between the first offset OTA sub-circuit and the second offset OTA sub-circuit; wherein plural input terminals of the first offset OTA sub-circuit, plural input terminals of the second offset OTA sub-circuit, and plural input terminals of the auxiliary offset circuit are connected in series, such that the common mode offset voltage of the offset OTA circuit equals a sum of the common mode offset voltage of the first offset OTA sub-circuit, the common mode offset voltage of the second offset OTA sub-circuit, and the auxiliary offset voltage.

[0008] In one preferred embodiment, the first offset OTA sub-circuit includes a follower amplification transistor, wherein an in-phase terminal, a control terminal, and an inverse-phase terminal of the follower amplification transistor respectively correspond to the first input terminal, the second input terminal, and the output terminal of the first offset OTA sub-circuit; wherein the common mode offset voltage of the first offset OTA sub-circuit is related to a conduction threshold voltage of the follower amplification transistor.

[0009] In one preferred embodiment, the amplification stage circuit includes a first amplification transistor, wherein a control terminal, an in-phase terminal, and an inverse-phase terminal of the first amplification transistor respectively correspond to the output terminal of the offset OTA circuit, a reference potential, and the first terminal of the clamping circuit.

[0010] In one preferred embodiment, the first amplification transistor and the follower amplification transistor are configured as a super follower circuit.

[0011] In one preferred embodiment, the common mode offset voltage of the first offset OTA sub-circuit and the auxiliary offset voltage have opposite voltage polarities, and the common mode offset voltage of the second offset OTA sub-circuit and the auxiliary offset voltage have opposite voltage polarities.

[0012] In one preferred embodiment, the auxiliary offset circuit includes an auxiliary offset transistor, wherein an inverse-phase terminal of the auxiliary offset transistor is electrically connected to its control terminal, wherein the auxiliary offset voltage is related to a conduction threshold voltage of the auxiliary offset transistor.

[0013] In one preferred embodiment, the auxiliary offset circuit further includes an auxiliary offset resistor serially connected with the auxiliary offset transistor, wherein the auxiliary offset resistor generates a portion of the auxiliary offset voltage based on an auxiliary offset current.

[0014] In one preferred embodiment, the second offset OTA sub-circuit includes a second amplification transistor, wherein a control terminal, an in-phase terminal, and an inverse-phase terminal of the second amplification transistor respectively correspond to the first input terminal and the second input terminal of the second offset OTA sub-circuit, and the output terminal of the offset OTA circuit.

[0015] In one preferred embodiment, the follower amplification transistor and the auxiliary offset transistor are first type of transistors, wherein the first amplification transistor and the second amplification transistor are second type of transistors, wherein an absolute value of a conduction threshold of the first type of transistors is less than an absolute value of a conduction threshold of the second type of transistors.

[0016] In one preferred embodiment, the offset OTA circuit further includes a bias transistor, wherein a control terminal thereof is coupled to the second amplification transistor; wherein the offset OTA circuit is configured as a common gate amplification circuit.

[0017] In one preferred embodiment, the second offset OTA sub-circuit includes a first differential transistor, a second differential transistor, and a common mode offset transistor; wherein an in-phase terminal and an inverse-phase terminal of the common mode offset transistor are respectively coupled to an in-phase terminal of the second differential transistor and an in-phase terminal of the first differential transistor, and a control terminal of the second differential transistor and a control terminal of the first differential transistor respectively correspond to the first input terminal and the second input terminal of the second offset OTA sub-circuit; wherein the first differential transistor and the second differential transistor are configured to differentially amplify the differential mode voltage between the first input terminal and the second input terminal of the second offset OTA sub-circuit, wherein the common mode offset voltage of the second offset OTA sub-circuit is related to a conduction threshold voltage of the common mode offset transistor.

[0018] In one preferred embodiment, the offset OTA circuit further includes a cascode transistor coupled between the inverse-phase terminal of the follower amplification transistor and the output terminal of the offset OTA circuit, wherein the cascode transistor is configured to bias the follower amplification transistor operating in a region with linear amplification characteristics.

[0019] From another perspective, the present invention provides an offset operational trans-conductance amplification (OTA) circuit for generating an output current at its output terminal based on a differential mode voltage between a first input terminal and a second input terminal thereof, wherein a common mode offset voltage is present between the first input terminal and the second input terminal thereof; the offset OTA circuit comprising: a first offset OTA sub-circuit having a common mode offset voltage between its first input terminal and its second input terminal, configured to generate the output current of the offset OTA circuit at the output terminal of the offset OTA circuit based on a differential mode voltage between the first input terminal and the second input terminal thereof; a second offset OTA sub-circuit having a common mode offset voltage between its first input terminal and its second input terminal, configured to generate the output current of the offset OTA circuit at the output terminal of the offset OTA circuit based on a differential mode voltage between the first input terminal and the second input terminal thereof; and an auxiliary offset circuit configured to generate an auxiliary offset voltage between the first offset OTA sub-circuit and the second offset OTA sub-circuit; wherein plural input terminals of the first offset OTA sub-circuit, plural input terminals of the second offset OTA sub-circuit, and plural input terminals of the auxiliary offset circuit are connected in series, such that the common mode offset voltage of the offset OTA circuit equals a sum of the common mode offset voltage of the first offset OTA sub-circuit, the common mode offset voltage of the second offset OTA sub-circuit, and the auxiliary offset voltage.

[0020] The objectives, technical details, features, and effects of the present invention will be better understood with regard to the detailed description of the embodiments below, with reference to the attached drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] FIG. 1A and FIG. 1B show schematic diagrams of clamping circuits from prior art.

[0022] FIG. 1C shows the characteristic curve of clamping current related to voltage for clamping circuits from prior art.

[0023] FIG. 2A and FIG. 2B show block diagrams of clamping circuits according to two embodiments of the present invention.

[0024] FIG. 3 shows a schematic diagram of a clamping circuit according to an embodiment of the present invention.

[0025] FIG. 4 shows a schematic diagram of a clamping circuit according to an embodiment of the present invention.

[0026] FIG. 5 shows a schematic diagram of a clamping circuit according to an embodiment of the present invention.

[0027] FIG. 6 shows a schematic diagram of a clamping circuit according to a specific embodiment of the present invention.

[0028] FIG. 7 shows a schematic diagram of a clamping circuit according to a specific embodiment of the present invention.

[0029] FIG. 8 shows a schematic diagram of an offset operational trans-conductance amplification (OTA) circuit in a clamping circuit according to a specific embodiment of the present invention.

[0030] FIG. 9 shows a schematic diagram of an offset OTA circuit in a clamping circuit according to a specific embodiment of the present invention.

[0031] FIG. 10 shows a schematic diagram of an offset OTA circuit in a clamping circuit according to a specific embodiment of the present invention.

[0032] FIG. 11 shows a schematic diagram of a second offset OTA sub-circuit in a clamping circuit according to a specific embodiment of the present invention.

[0033] FIG. 12 shows a schematic diagram of an offset OTA circuit in a clamping circuit according to a specific embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0034] The drawings as referred to throughout the description of the present invention are for illustration only, to show the interrelations between the circuits and the signal waveforms, but not drawn according to actual scale of circuit sizes and signal amplitudes and frequencies.

[0035] FIG. 2A and FIG. 2B show block diagrams of clamping circuits according to two embodiments of the present invention. In one embodiment, as shown in FIG. 2A, the clamping circuit **1002A** is configured to clamp a voltage difference V_{diff} between its first terminal TP_{clp} (e.g., the positive terminal) and its second terminal TN_{clp} (e.g., the negative terminal) so as not to exceed a clamping voltage level V_{clp} . In the embodiment of FIG. 2A, the first terminal TP_{clp} and the second terminal TN_{clp} of the clamping circuit **1002A** are respectively coupled to the gate and the source of a transistor **Q0**, thereby clamping the gate-source voltage of the transistor **Q0** not to exceed the clamping voltage level V_{clp} . The transistor **Q0** is, for example, an N-type metal oxide semiconductor (MOS) transistor. In one embodiment, the clamping circuit **1002A** includes: an offset operational trans-conductance amplification (OTA) circuit **100** and an amplification stage circuit **200**.

[0036] In one embodiment, the offset OTA circuit **100** is configured to generate an output current IO_{tt} at its output terminal TO_{tt} according to a differential mode voltage between its first input terminal IP_{tt} and its second input terminal IN_{tt} . In this embodiment, a common mode offset voltage VOS_{tt} is present between the first input terminal IP_{tt} and the second input terminal IN_{tt} of the offset OTA circuit **100**. The first input terminal IP_{tt} and the second input terminal IN_{tt} of the offset OTA circuit **100** are respectively coupled to the first terminal TP_{clp} and the second terminal TN_{clp} of the clamping circuit **1002A**.

[0037] It should be noted that, in one embodiment, the first input terminal IP_{tt} of the offset OTA

circuit **100** corresponds to its positive input terminal, and the second input terminal IN_{tt} corresponds to its negative input terminal. It should also be noted that the common mode offset voltage VOS_{tt} is the offset voltage inherent to the offset OTA circuit **100** itself. Therefore, the differential mode voltage between the first input terminal IP_{tt} and the second input terminal IN_{tt} of the offset OTA circuit **100** equals the voltage difference between the first input terminal IP_{tt} and the second input terminal IN_{tt} subtracting the common mode offset voltage VOS_{tt} .

[0038] In one embodiment, the amplification stage circuit **200** is coupled between the output terminal TO_{tt} and the first input terminal IP_{tt} of the offset OTA circuit **100**. In one embodiment, the amplification stage circuit **200** is configured to generate a first terminal voltage VTP_{clp} at the first terminal TP_{clp} of the clamping circuit **1002A** according to the output current IO_{tt} of the offset OTA circuit **100**, in order to clamp the voltage difference V_{diff} of the clamping circuit **1002A** not to exceed the clamping voltage level V_{clp} . In one embodiment, the clamping voltage level V_{clp} corresponds to the common mode offset voltage VOS_{tt} of the offset OTA circuit **100**.

[0039] In one embodiment, as shown in FIG. 2B, a first terminal TP_{clp} and a second terminal TN_{clp} of the clamping circuit **1002B** are respectively coupled to the source and gate of a transistor $Q0'$, thereby clamping the gate-source voltage of transistor $Q0'$ at the clamping voltage level V_{clp} . The transistor $Q0'$ is, for example, a P-type metal oxide semiconductor (MOS) transistor. The operational details of the clamping circuit **1002B** can be inferred from the description of FIG. 2A and are not elaborated here. From FIG. 2A and FIG. 2B, it can be understood that the clamping circuit of the present invention can be used to clamp both NMOS and PMOS transistors. The following embodiments are described taking the clamping of NMOS transistor as examples, but this does not limit the scope of the present invention.

[0040] FIG. 3 shows a block diagram of a clamping circuit according to an embodiment of the present invention. In one embodiment, an offset OTA circuit **103** in the clamping circuit **1003** includes: a first offset OTA sub-circuit **130**, a second offset OTA sub-circuit **150**, and an auxiliary offset circuit **300**. In one embodiment, the first offset OTA sub-circuit **130** has a common mode offset voltage VOS_{A1} between its first input terminal IP_{A1} and its second input terminal IN_{A1} . The first offset OTA sub-circuit **130** is configured to generate an output current IO_{A1} according to the differential mode voltage between its first input terminal IP_{A1} and its second input terminal IN_{A1} . In this embodiment, the first input terminal IP_{A1} of the aforementioned first offset OTA sub-circuit **130** corresponds to its positive input terminal, and the second input terminal IN_{A1} of the first offset OTA sub-circuit **130** corresponds to its negative input terminal, and the first input terminal IP_{A1} of the first offset OTA sub-circuit **130** is coupled to the first input terminal IP_{tt} of the offset OTA circuit **103**.

[0041] In one embodiment, as shown in FIG. 3, the second offset OTA sub-circuit **150** has a common mode offset voltage VOS_{A2} between its first input terminal IP_{A2} and its second input terminal IN_{A2} . The second offset OTA sub-circuit **150** is configured to generate an output current IO_{A2} at its output terminal TO_{tt} based on a differential mode voltage between its first input terminal IP_{A2} and its second input terminal IN_{A2} . In this embodiment, the first input terminal IP_{A2} of the second offset OTA sub-circuit **150** corresponds to its positive input terminal, and the second input terminal IN_{A2} corresponds to its negative input terminal. The second input terminal IN_{A2} of the second offset OTA sub-circuit **150** is coupled to the second input terminal IN_{tt} of the offset OTA circuit **103**. In this embodiment, the output terminal TO_{tt} of the offset OTA circuit **103** is configured to generate an output current IO_{tt} of the offset OTA circuit **103** based on the output currents IO_{A1} and IO_{A2} . In one embodiment, the output current IO_{tt} of the offset OTA circuit **103** is a linear superposition of the output currents IO_{A1} and IO_{A2} .

[0042] In one embodiment, the auxiliary offset circuit **300** is configured to generate an auxiliary offset voltage VOS_{sh} between the first offset OTA sub-circuit **130** and the second offset OTA sub-circuit **150**. In one embodiment, the plural input terminals of the first offset OTA sub-circuit **130**, the plural input terminals of the second offset OTA sub-circuit **150**, and the plural input terminals

of the auxiliary offset circuit **300** are interconnected in series. Specifically, in this embodiment, the second input terminal IN_A2 of the first offset OTA sub-circuit **130** and a first terminal TP_sh (e.g., the positive terminal) of the auxiliary offset circuit **300** are connected in series, and a second terminal TN_sh (e.g., the negative terminal) of the auxiliary offset circuit **300** and the first input terminal IP_A2 of the second offset OTA sub-circuit **150** are connected in series, such that, the common mode offset voltage VOS_tt of the offset OTA circuit **103** equals a sum of the common mode offset voltage VOS_A1 of the first offset OTA sub-circuit **130**, the common mode offset voltage VOS_A2 of the second offset OTA sub-circuit **150**, and the auxiliary offset voltage VOS_sh.

[0043] FIG. **4** shows a schematic diagram of a clamping circuit according to an embodiment of the present invention. An offset OTA circuit **104** of the clamping circuit **1004** in FIG. **4** corresponds to a specific embodiment of the offset OTA circuit **103** shown in FIG. **3**. In one embodiment, a first offset OTA sub-circuit **134** in the offset OTA circuit **104** includes a follower amplification transistor Q2. In this embodiment, the follower amplification transistor Q2 is a PMOS transistor; however, this is not to limit the scope of the present invention, as in other embodiments, the follower amplification transistor Q2 could also be configured as a bipolar junction transistor (BJT), and the same applies to other transistors mentioned herein. In one embodiment, an in-phase terminal (source), a control terminal (gate), and an inverse-phase terminal (drain) of the follower amplification transistor Q2 respectively correspond to the first input terminal IP_A1 and the second input terminal IN_A1 of the first offset OTA sub-circuit **134**, and the output terminal TO_tt of the offset OTA circuit **104**. The common mode offset voltage VOS_A1 of the first offset OTA sub-circuit **134** is related to a conduction threshold voltage Vt_Q2 of the follower amplification transistor Q2, wherein in this embodiment, the common mode offset voltage VOS_A1 of the first offset OTA sub-circuit **134** equals the conduction threshold voltage Vt_Q2 of the follower amplification transistor Q2. In this embodiment, the follower amplification transistor Q2 is configured as a source follower.

[0044] FIG. **5** shows a schematic diagram of a clamping circuit according to an embodiment of the present invention. The clamping circuit **1005** in FIG. **5** corresponds to a specific embodiment of the clamping circuit **1003** shown in FIG. **3**. The clamping circuit **1005** is similar to the clamping circuit **1004** shown in FIG. **4**, and in this embodiment, an amplification stage circuit **205** in the clamping circuit **1005** includes a first amplification transistor Q1. In this embodiment, the first amplification transistor Q1 is an NMOS transistor. A control terminal (gate), an in-phase terminal (source), and an inverse-phase terminal (drain) of the first amplification transistor Q1 respectively correspond to the output terminal TO_tt of the offset OTA circuit **104**, a reference potential (in this embodiment, ground potential), and the first terminal TP_clp of the clamping circuit **1005**. It should be noted that the aforementioned reference potential can be either a ground potential or a supply voltage potential.

[0045] In one embodiment, as shown in FIG. **5**, the first amplification transistor Q1 and the follower amplification transistor Q2 are configured as a super follower circuit **250**. In one embodiment, the super follower circuit is formed by amplifying the signal from the inverting terminal of the follower circuit through an inverting amplifier stage, and then feeding the amplified signal back to the non-inverting end of the follower circuit. Specifically, in the embodiment of FIG. **5**, the signal at the inverse-phase terminal (drain) of the follower amplification transistor Q2 is amplified by the first amplification transistor Q1, and the amplified signal is then fed back to its in-phase terminal (source) of the follower amplification transistor Q2 to form the super follower circuit **250**.

[0046] It should be noted that, by the configuration of the aforementioned super follower circuit **250**, the follower effect of the follower amplification transistor Q2 is enhanced. That is, when the clamping circuit **1005** is activated, it can regulate the gate-source voltage of the follower amplification transistor Q2 closer to and approximately fixed at its conduction threshold voltage

Vt_Q2. Thus, when the voltage difference Vdiff reaches the clamping voltage level Vclp, it is clamped close to but not exceeding the clamping voltage level Vclp, without leakage currents (as indicated by the ideal state shown by the long dashed line in FIG. 1C), thereby achieving precise clamping, power saving, high efficiency, and high stability. The various specific embodiments described in the following sections can also achieve the aforementioned effects.

[0047] FIG. 6 shows a schematic diagram of a clamping circuit according to a specific embodiment of the present invention. The clamping circuit **1006** in FIG. 6 is similar to the clamping circuit **1005** in FIG. 5. Compared to the clamping circuit **1005** in FIG. 5, in one embodiment, within an offset OTA circuit **106**, a second offset OTA sub-circuit **156** includes a second amplification transistor **Q3**. In one embodiment, an auxiliary offset circuit **306** includes plural current sources and a first offset resistor Ros1. The auxiliary offset voltage VOS_sh is the product of the current sources and the resistance value of the first offset resistor Ros1. In this embodiment, the second amplification transistor **Q3** is an NMOS transistor, with its control terminal (gate), in-phase terminal (source), and inverse-phase terminal (drain) respectively corresponding to the first input terminal IP_A2 and the second input terminal IN_A2 of the second offset OTA sub-circuit **156**, and the output terminal TO_tt of the offset OTA circuit **106**.

[0048] From one perspective, FIG. 6 is a specific embodiment of FIG. 3. As shown in FIG. 6, the second input terminal IN_A1 (corresponding to the gate of the follower amplification transistor **Q2**) of the first offset OTA sub-circuit is serially connected with the first terminal TP_sh (corresponding to the positive terminal) of the auxiliary offset circuit **306**, and the second terminal TN_sh (corresponding to the negative terminal) of the auxiliary offset circuit **306** is serially connected with the first input terminal IP_A2 (corresponding to the gate of the second amplification transistor **Q3**) of the second offset OTA sub-circuit **156**. In the embodiment of FIG. 6, the gate-source voltage of the transistor **Q0** is clamped to not exceed a sum of a conduction threshold voltage Vt_Q3 of the second amplification transistor **Q3**, the auxiliary offset voltage VOS_sh, and the conduction threshold voltage Vt_Q2 of the follower amplification transistor **Q2**, that is, in this embodiment, the clamping voltage level Vclp can be expressed by the following equation 1.

[00001] $V_{clp} = V_{t_Q3} + V_{OS_sh} + V_{t_Q2}$ (equation1)

[0049] FIG. 7 shows a schematic diagram of a clamping circuit according to a specific embodiment of the present invention. The clamping circuit **1007** of FIG. 7 is similar to the clamping circuit **1006** of FIG. 6. Compared to the clamping circuit **1006** of FIG. 6, in one embodiment, within the offset OTA circuit **107**, an auxiliary offset circuit **307** is connected in the opposite direction to the serial connection of the first and second offset OTA sub-circuits. Specifically, the gate of the follower amplification transistor **Q2** is coupled to the second terminal TN_sh (corresponding to the negative terminal) of the auxiliary offset circuit **307**, and the first terminal TP_sh (corresponding to the positive terminal) of the auxiliary offset circuit **307** is coupled to the gate of the second amplification transistor **Q3**.

[0050] In one embodiment, as shown in FIG. 7, the common mode offset voltage VOS_A1 (corresponding to the conduction threshold voltage Vt_Q2 of the follower amplification transistor **Q2**) of the first offset OTA sub-circuit and the auxiliary offset voltage VOS_sh have opposite voltage polarities. Besides, the common mode offset voltage VOS_A2 (corresponding to the conduction threshold voltage Vt_Q3 of the second amplification transistor **Q3**) of the second offset OTA sub-circuit and the auxiliary offset voltage VOS_sh have opposite voltage polarities. In this embodiment, the clamping voltage level Vclp can be expressed by the following equation 2.

[00002] $V_{clp} = V_{t_Q3} + (-V_{OS_sh}) + V_{t_Q2}$ (equation2)

[0051] FIG. 8 shows a schematic diagram of an offset operational trans-conductance amplification (OTA) circuit in a clamping circuit according to a specific embodiment of the present invention. The clamping circuit **1008** of FIG. 8 is similar to the clamping circuit **1007** of FIG. 7. Compared to

the clamping circuit **1007** of FIG. 7, in this embodiment, as shown in an offset OTA circuit **108** of FIG. 8, the auxiliary offset circuit **308** includes an auxiliary offset transistor Q5. In one embodiment, the auxiliary offset transistor Q5 is a PMOS transistor, and its inverse-phase terminal (drain) is electrically connected to its control terminal (gate). The auxiliary offset voltage VOS_sh is related to the conduction threshold voltage Vt_Q5 of the auxiliary offset transistor Q5. In this embodiment, the auxiliary offset voltage VOS_sh equals to the conduction threshold voltage Vt_Q5 of the auxiliary offset transistor Q5.

[0052] It should be noted that in the embodiment shown in FIG. 8, the follower amplification transistor Q2 and the auxiliary offset transistor Q5 are first type of transistors (for example, PMOS transistors with low conduction threshold voltages), and the first amplification transistor Q1 and the second amplification transistor Q3 are second type of transistors (for example, NMOS transistors with standard conduction threshold voltages), wherein n the absolute value of the conduction threshold of the first type of transistors is less than that of the second type of transistors. Specifically, in this embodiment, the clamping voltage level Vclp can be expressed by the following equation 3.

[00003] $V_{clp} = V_{t_Q3} + (-V_{t_Q5}) + V_{t_Q2}$ (equation3)

[0053] From the above equation 3, it can be seen that the configuration of the conduction thresholds of the first type and second type transistors ensures that the current sources in the auxiliary offset circuit **308** remain conductive.

[0054] FIG. 9 shows a schematic diagram of an offset OTA circuit in a clamping circuit according to a specific embodiment of the present invention. The clamping circuit **1009** in FIG. 9 is similar to the clamping circuit **1008** in FIG. 8, and in this embodiment, as shown in FIG. 9, the auxiliary offset circuit **309** further includes a bias transistor Q4. In this embodiment, the bias transistor Q4 is an NMOS transistor, and its control terminal (gate) is coupled to the second amplification transistor Q3, thereby configuring the offset OTA circuit **109** as a common gate amplification circuit. In one embodiment, the common gate amplification circuit configured in the offset OTA circuit **109** is used to provide a reference voltage (namely the gate voltage of the follower amplification transistor Q2) for the super follower circuit **250** (including the first amplification transistor Q1 and the follower amplification transistor Q2).

[0055] FIG. 10 shows a schematic diagram of an offset OTA circuit in a clamping circuit according to a specific embodiment of the present invention. The clamping circuit **1010** in FIG. 10 is similar to the clamping circuit **1009** in FIG. 9. Compared to the clamping circuit **1009** in FIG. 9, in this embodiment, within an offset OTA circuit **110** as shown in FIG. 10, the auxiliary offset circuit **310** further includes an auxiliary offset resistor Ros serially connected with the auxiliary offset transistor Q5. In one embodiment, the auxiliary offset resistor Ros generates a portion of the auxiliary offset voltage VOS_sh based on the auxiliary offset current Ios.

[0056] It should be noted that the embodiment shown in FIG. 10 is more cost-effective compared to the embodiment shown in FIG. 8. Specifically, in the embodiment shown in FIG. 10, the auxiliary offset resistor Ros is used to maintain the operation of the auxiliary offset circuit **310**. In this embodiment, allowing the absolute values of the conduction thresholds of the follower amplification transistor Q2 and the auxiliary offset transistor Q5 to not be less than the absolute values of the conduction thresholds of the first amplification transistor Q1 and the second amplification transistor Q3, i.e., allowing the follower amplification transistor Q2 and the auxiliary offset transistor Q5 to be PMOS transistors with standard conduction threshold voltages, thereby reducing the fabrication costs of the follower amplification transistor Q2 and the auxiliary offset transistor Q5.

[0057] FIG. 11 shows a schematic diagram of a second offset OTA sub-circuit in a clamping circuit according to a specific embodiment of the present invention. The clamping circuit **1011** in FIG. 11 is similar to the clamping circuit **1009** in FIG. 9. Compared to the clamping circuit **1009** in FIG. 9,

in one embodiment, a second offset OTA sub-circuit **151** in the offset OTA circuit **111** includes a first differential transistor **Q21**, a second differential transistor **Q22**, and a common mode offset transistor **Q23**. In this embodiment, the first differential transistor **Q21** and the second differential transistor **Q22** are PMOS transistors, and the common mode offset transistor **Q23** is an NMOS transistor.

[0058] In one embodiment, as shown in FIG. **11**, the common mode offset transistor **Q23** is configured as a diode-connected transistor, i.e., its gate is electrically connected to its drain. An in-phase terminal (source) and an inverse-phase (drain) of the common mode offset transistor **Q23** are respectively coupled to an in-phase terminal (source) of the second differential transistor **Q22** and an in-phase terminal (source) of the first differential transistor **Q21**, and the control terminal (gate) of the second differential transistor **Q22** and the control terminal (gate) of the first differential transistor **Q21** respectively correspond to the first input terminal **IP_A2** and the second input terminal **IN_A2** of the second offset OTA sub-circuit **151**. In one embodiment, the first differential transistor **Q21** and the second differential transistor **Q22** are used to differentially amplify the differential voltage between the first input terminal **IP_A2** and the second input terminal **IN_A2** of the second offset OTA sub-circuit **151**. The common mode offset voltage **VOS_A2** of the second offset OTA sub-circuit **151** is related to the conduction threshold voltage V_{t_Q23} of the common mode offset transistor **Q23**.

[0059] It should be noted that in the embodiment shown in FIG. **11**, since the first input terminal **IP_A2** and the second input terminal **IN_A2** of the second offset OTA sub-circuit **151** are both coupled to the gates of PMOS transistors, even if the common mode voltage between the first input terminal **IP_A2** and the second input terminal **IN_A2** of the second offset OTA sub-circuit **151** is low, the second offset OTA sub-circuit **151** can still operate. However, in the embodiment where the second offset OTA sub-circuit is configured as the second amplification transistor **Q3**, the voltage difference between the first input terminal **IP_A2** and the second input terminal **IN_A2** of the second offset OTA sub-circuit must be greater than the conduction threshold voltage V_{t_Q3} of the second amplification transistor **Q3** for the second offset OTA sub-circuit to activate, i.e., the common mode voltage at the first input terminal **IP_A2** of the second offset OTA sub-circuit is limited. Therefore, the embodiment shown in FIG. **11** is more suitable for applications including low common mode input voltages compared to the previous embodiments.

[0060] FIG. **12** shows a schematic diagram of an offset OTA circuit in a clamping circuit according to a specific embodiment of the present invention. The clamping circuit **1012** in FIG. **12** is similar to the clamping circuit **1010** in FIG. **10**. Compared to the clamping circuit **1010** in FIG. **10**, in this embodiment, an offset OTA circuit **112** of the clamping circuit **1012** further includes cascode transistors **Q6~Q10**. In one embodiment, the cascode transistor **Q7** is coupled between the inverse-phase (drain) of the follower amplification transistor **Q2** and the output terminal **TO_tt** of the offset OTA circuit **112**, wherein the cascode transistor **Q7** is configured to bias the follower amplification transistor **Q2** operating in an operation region with characteristic of linear amplification, in this embodiment, to ensure that the follower amplification transistor **Q2**, as a MOS transistor, operates in the saturation region.

[0061] It should be noted that in the embodiment shown in FIG. **10**, because the gate-source voltage of the transistor **Q0** is close to the gate-source voltage of the first amplification transistor **Q1**, the drain-source voltage of the follower amplification transistor **Q2** is lower, thereby possibly operating in the linear region of MOS transistor and resulting in a lower gain of the super follower circuit **250** (including the first amplification transistor **Q1** and the follower amplification transistor **Q2**). In the embodiment shown in FIG. **12**, by configuring the cascode transistors **Q6~Q10**, the drain-source voltage of the follower amplification transistor **Q2** is increased, thereby ensuring that the follower amplification transistor **Q2** operates in the saturation region of MOS transistor and enhancing the gain of the super follower circuit **250**. Overall, the gain in the embodiment shown in FIG. **12** is superior to the previous embodiments, thus the clamping circuit **1012** in FIG. **12**

achieves more precise clamping and other benefits.

[0062] The present invention has been described in considerable detail with reference to certain preferred embodiments thereof. It should be understood that the description is for illustrative purpose, not for limiting the broadest scope of the present invention. An embodiment or a claim of the present invention does not need to achieve all the objectives or advantages of the present invention. The title and abstract are provided for assisting searches but not for limiting the scope of the present invention. Those skilled in this art can readily conceive variations and modifications within the spirit of the present invention. For example, to perform an action “according to” a certain signal as described in the context of the present invention is not limited to performing an action strictly according to the signal itself, but can be performing an action according to a converted form or a scaled-up or down form of the signal, i.e., the signal can be processed by a voltage-to-current conversion, a current-to-voltage conversion, and/or a ratio conversion, etc. before an action is performed. It is not limited for each of the embodiments described hereinbefore to be used alone; under the spirit of the present invention, two or more of the embodiments described hereinbefore can be used in combination. For example, two or more of the embodiments can be used together, or, a part of one embodiment can be used to replace a corresponding part of another embodiment. In view of the foregoing, the spirit of the present invention should cover all such and other modifications and variations, which should be interpreted to fall within the scope of the following claims and their equivalents.

Claims

1. A clamping circuit for clamping a voltage difference between a first terminal and a second terminal of the clamping circuit so as not to exceed a clamping voltage level, comprising: an offset operational trans-conductance amplification (OTA) circuit configured to generate an output current at its output terminal according to a differential mode voltage between a first input terminal and a second input terminal, wherein a common mode offset voltage is present between the first input terminal and the second input terminal thereof, wherein the first input terminal and the second input terminal of the offset OTA circuit are respectively coupled to the first terminal and the second terminal of the clamping circuit; and an amplification stage circuit coupled between the output terminal and the first input terminal of the offset OTA circuit, configured to generate a first terminal voltage at the first terminal of the clamping circuit according to the output current of the offset OTA circuit, so as to clamp the voltage difference of the clamping circuit to not exceed the clamping voltage level; wherein the clamping voltage level corresponds to the common mode offset voltage of the offset OTA circuit; wherein the offset OTA circuit includes: a first offset OTA sub-circuit having a common mode offset voltage between its first input terminal and its second input terminal, configured to generate the output current of the offset OTA circuit at the output terminal of the offset OTA circuit based on a differential mode voltage between the first input terminal and the second input terminal thereof; a second offset OTA sub-circuit having a common mode offset voltage between its first input terminal and its second input terminal, configured to generate the output current of the offset OTA circuit at the output terminal of the offset OTA circuit based on a differential mode voltage between the first input terminal and the second input terminal thereof; and an auxiliary offset circuit configured to generate an auxiliary offset voltage between the first offset OTA sub-circuit and the second offset OTA sub-circuit; wherein plural input terminals of the first offset OTA sub-circuit, plural input terminals of the second offset OTA sub-circuit, and plural input terminals of the auxiliary offset circuit are connected in series, such that the common mode offset voltage of the offset OTA circuit equals a sum of the common mode offset voltage of the first offset OTA sub-circuit, the common mode offset voltage of the second offset OTA sub-circuit, and the auxiliary offset voltage.

2. The clamping circuit of claim 1, wherein the first offset OTA sub-circuit includes a follower

amplification transistor, wherein an in-phase terminal, a control terminal, and an inverse-phase terminal of the follower amplification transistor respectively correspond to the first input terminal, the second input terminal, and the output terminal of the first offset OTA sub-circuit; wherein the common mode offset voltage of the first offset OTA sub-circuit is related to a conduction threshold voltage of the follower amplification transistor.

3. The clamping circuit of claim 2, wherein the amplification stage circuit includes a first amplification transistor, wherein a control terminal, an in-phase terminal, and an inverse-phase terminal of the first amplification transistor respectively correspond to the output terminal of the offset OTA circuit, a reference potential, and the first terminal of the clamping circuit.

4. The clamping circuit of claim 3, wherein the first amplification transistor and the follower amplification transistor are configured as a super follower circuit.

5. The clamping circuit of claim 3, wherein the common mode offset voltage of the first offset OTA sub-circuit and the auxiliary offset voltage have opposite voltage polarities, and the common mode offset voltage of the second offset OTA sub-circuit and the auxiliary offset voltage have opposite voltage polarities.

6. The clamping circuit of claim 3, wherein the auxiliary offset circuit includes an auxiliary offset transistor, wherein an inverse-phase terminal of the auxiliary offset transistor is electrically connected to its control terminal, wherein the auxiliary offset voltage is related to a conduction threshold voltage of the auxiliary offset transistor.

7. The clamping circuit of claim 6, wherein the auxiliary offset circuit further includes an auxiliary offset resistor serially connected with the auxiliary offset transistor, wherein the auxiliary offset resistor generates a portion of the auxiliary offset voltage based on an auxiliary offset current.

8. The clamping circuit of claim 6, wherein the second offset OTA sub-circuit includes a second amplification transistor, wherein a control terminal, an in-phase terminal, and an inverse-phase terminal of the second amplification transistor respectively correspond to the first input terminal and the second input terminal of the second offset OTA sub-circuit, and the output terminal of the offset OTA circuit.

9. The clamping circuit of claim 8, wherein the follower amplification transistor and the auxiliary offset transistor are first type of transistors, wherein the first amplification transistor and the second amplification transistor are second type of transistors, wherein an absolute value of a conduction threshold of the first type of transistors is less than an absolute value of a conduction threshold of the second type of transistors.

10. The clamping circuit of claim 8, wherein the offset OTA circuit further includes a bias transistor, wherein a control terminal thereof is coupled to the second amplification transistor; wherein the offset OTA circuit is configured as a common gate amplification circuit.

11. The clamping circuit of claim 6, wherein the second offset OTA sub-circuit includes a first differential transistor, a second differential transistor, and a common mode offset transistor; wherein an in-phase terminal and an inverse-phase terminal of the common mode offset transistor are respectively coupled to an in-phase terminal of the second differential transistor and an in-phase terminal of the first differential transistor, and a control terminal of the second differential transistor and a control terminal of the first differential transistor respectively correspond to the first input terminal and the second input terminal of the second offset OTA sub-circuit; wherein the first differential transistor and the second differential transistor are configured to differentially amplify the differential mode voltage between the first input terminal and the second input terminal of the second offset OTA sub-circuit, wherein the common mode offset voltage of the second offset OTA sub-circuit is related to a conduction threshold voltage of the common mode offset transistor.

12. The clamping circuit of claim 8, wherein the offset OTA circuit further includes a cascode transistor coupled between the inverse-phase terminal of the follower amplification transistor and the output terminal of the offset OTA circuit, wherein the cascode transistor is configured to bias the follower amplification transistor operating in a region with linear amplification characteristics.

13. An offset operational trans-conductance amplification (OTA) circuit for generating an output current at its output terminal based on a differential mode voltage between a first input terminal and a second input terminal thereof, wherein a common mode offset voltage is present between the first input terminal and the second input terminal thereof; the offset OTA circuit comprising: a first offset OTA sub-circuit having a common mode offset voltage between its first input terminal and its second input terminal, configured to generate the output current of the offset OTA circuit at the output terminal of the offset OTA circuit based on a differential mode voltage between the first input terminal and the second input terminal thereof; a second offset OTA sub-circuit having a common mode offset voltage between its first input terminal and its second input terminal, configured to generate the output current of the offset OTA circuit at the output terminal of the offset OTA circuit based on a differential mode voltage between the first input terminal and the second input terminal thereof; and an auxiliary offset circuit configured to generate an auxiliary offset voltage between the first offset OTA sub-circuit and the second offset OTA sub-circuit; wherein plural input terminals of the first offset OTA sub-circuit, plural input terminals of the second offset OTA sub-circuit, and plural input terminals of the auxiliary offset circuit are connected in series, such that the common mode offset voltage of the offset OTA circuit equals a sum of the common mode offset voltage of the first offset OTA sub-circuit, the common mode offset voltage of the second offset OTA sub-circuit, and the auxiliary offset voltage.

14. The offset OTA circuit of claim 13, wherein the first offset OTA sub-circuit includes a follower amplification transistor, wherein an in-phase terminal, a control terminal, and an inverse-phase terminal of the follower amplification transistor respectively correspond to the first input terminal, the second input terminal, and the output terminal of the first offset OTA sub-circuit; wherein the common mode offset voltage of the first offset OTA sub-circuit is related to a conduction threshold voltage of the follower amplification transistor.

15. The offset OTA circuit of claim 13, wherein the common mode offset voltage of the first offset OTA sub-circuit and the auxiliary offset voltage have opposite voltage polarities, and the common mode offset voltage of the second offset OTA sub-circuit and the auxiliary offset voltage have opposite voltage polarities.

16. The offset OTA circuit of claim 13, wherein the auxiliary offset circuit includes an auxiliary offset transistor, wherein an inverse-phase terminal of the auxiliary offset transistor is electrically connected to its control terminal; wherein the auxiliary offset voltage is related to a conduction threshold voltage of the auxiliary offset transistor.

17. The offset OTA circuit of claim 16, wherein the auxiliary offset circuit further includes an auxiliary offset resistor serially connected with the auxiliary offset transistor, wherein the auxiliary offset resistor generates a portion of the auxiliary offset voltage based on an auxiliary offset current.

18. The offset OTA circuit of claim 16, wherein the second offset OTA sub-circuit includes an amplification transistor, wherein a control terminal, an in-phase terminal, and an inverse-phase terminal of the amplification transistor respectively correspond to the first input terminal and the second input terminal of the second offset OTA sub-circuit, and the output terminal of the offset OTA circuit.

19. The offset OTA circuit of claim 18, wherein the follower amplification transistor and the auxiliary offset transistor are first type of transistors, wherein the amplification transistor are second type of transistors, wherein an absolute value of a conduction threshold of the first type of transistors is less than an absolute value of a conduction threshold of the second type of transistors.

20. The offset OTA circuit of claim 18, further comprising a bias transistor, wherein a control terminal thereof is coupled to the amplification transistor; wherein the offset OTA circuit is configured as a common gate amplification circuit.

21. The offset OTA circuit of claim 16, wherein the second offset OTA sub-circuit includes a first differential transistor, a second differential transistor, and a common mode offset transistor;

wherein an in-phase terminal and an inverse-phase terminal of the common mode offset transistor are respectively coupled to an in-phase terminal of the second differential transistor and an in-phase terminal of the first differential transistor, and a control terminal of the second differential transistor and a control terminal of the first differential transistor respectively correspond to the first input terminal and the second input terminal of the second offset OTA sub-circuit; wherein the first differential transistor and the second differential transistor are configured to differentially amplify the differential mode voltage between the first input terminal and the second input terminal of the second offset OTA sub-circuit; wherein the common mode offset voltage of the second offset OTA sub-circuit is related to a conduction threshold voltage of the common mode offset transistor.

22. The offset OTA circuit of claim 18, further includes a cascode transistor, coupled between the inverse-phase terminal of the follower amplification transistor and the output terminal of the offset OTA circuit, wherein the cascode transistor is configured to bias the follower amplification transistor operating in a region with linear amplification characteristics.
