

LEVEL-SHIFTER FOR
EXTREMELY LOW POWER SUPPLY

TECHNICAL FIELD

5 This invention relates generally to level shifter circuitry and more particularly, it relates to an improved level shifter circuit for use with an extremely low power supply voltage.

BACKGROUND ART

10 As is generally well-known, digital logic circuits are widely used in the areas of electronics and computer-type equipment. However, the various digital logic circuits that must communicate with one another may have different power supply voltages. For example, a first circuit that operates with logic levels between 0 V (L) and 2.0 V (H)
15 may need to communicate with a second circuit that operates with logic levels between 0 V (L) and 3.3 V (H). Thus, when a first digital logic circuit of one power supply voltage is required to interface with a second digital logic circuit of another power supply voltage there is typically needed a voltage conversion or translation between the two
20 different power supplies so that they will be compatible with each other and not drain static current. A level shifter circuit is provided to perform this function.

In Figure 1, there is shown a schematic circuit diagram of a prior art level shifter circuit **10** which may be used to perform a
25 voltage conversion. The level shifter circuit **10** is comprised of a pass N-channel MOS transistor **N1**; pull-up P-channel MOS transistors **P1**, **P2**; and pull-down N-channel MOS transistors **N4**, **N5**. The first P-channel transistor **P1** has its source connected to the source of the second P-channel transistor **P2** and to a high voltage **HV**, which is
30 typically at approximately VCC - +10 volts. The drain of the transistor **P1** is connected to the gate of the transistor **P2** and to the source of the pass transistor **N1**. The gate of the transistor **P1** is connected to the drain of the transistor **P2** at a node **A**, which is connected to an output terminal **OUT**.

35 The pass transistor **N1** has its drain connected to an input terminal **IN** for receiving an input signal and to the gate of the pull-down transistor **N5**. The gate of the transistor **N1** is connected to a first power supply potential **VCC**, which is typically at +2.0 V. The

pull-down transistor **N4** has its drain connected also to the node **A** and to the output terminal **OUT**. The pull-down transistor **N5** has its drain connected to the source of the transistor **N4** and its source connected to a second power supply or ground potential **VSS** (zero volts). The n-type substrate of the P-channel transistors **P1**, **P2** is tied to its source and to the high voltage **HV**.

In operation, when the input signal at the input terminal **IN** is at 0 volts the pull-up transistor **P2** will be turned ON and the transistors **P1** and **N5** will both be turned OFF. As a result, the level shifter circuit **10** will produce a voltage level of **HV** (i.e., +9 V) at the output terminal **OUT**. On the other hand, when the input signal at the input terminal **IN** is at **VCC** (i.e., 2.0 V), the transistors **N5** and **P1** will both be turned ON and the transistor **P2** will be turned OFF. Thus, the level shifter circuit **10** will provide a voltage level of 0 volts at the output terminal **OUT**.

However, this existing prior art level shifter circuit **10** suffers from the principal disadvantage that it will fail or not operate when the power supply voltage **VCC** is reduced down to an extremely low voltage, such as +1.0 volts which is equivalent to the threshold voltage of the P-channel MOS transistors **P1**, **P2** and **HV = VCC**. In view of the trend for deep-submicron CMOS technology, lower and lower power supply voltages **VCC** are being used. Thus, as the power supply voltage **VCC** is made lower to be near or below the threshold voltage of the P-channel transistors **P1**, **P2** and the high voltage **HV** is made to be equal to the supply potential **VCC**, neither of the pull-up transistors **P1** or **P2** will be able to be turned ON and consequently, the node **A** or output terminal **OUT** will be left floating.

Further, as the thickness of the gate oxides for forming the CMOS transistors are being made thinner and thinner in the CMOS technology, such as 60 Å (angstrom) or below, a voltage difference higher than about +2.4 V - +2.5 V applied across the gate and the bulk of the transistor device will cause a breakdown in the gate oxide to occur, thereby creating a failure. For example, when the input signal of 0 volts is applied to the gate of the transistor **P2** in Figure 1, the level shifter circuit **10** will generate a voltage level of **HV** volts at the output terminal **OUT**. As will be noted, there will be created a voltage difference of **HV** between the drains and the gates of the P-

channel transistors **P1**, **P2**. If the transistors **P1**, **P2** were made of thin oxide, this will cause a breakdown of the thinner gate oxides.

Therefore, it would be desirable to provide an improved level shifter circuit which is designed to be capable of operating with an extremely low power supply voltage. Further, it would be expedient that the level shifter circuit be able to prevent the breakdown of the gate oxide in all of the transistors.

DISCLOSURE OF INVENTION

Accordingly, it is a general technical advantage of the present invention to provide an improved level shifter circuit for use with an extremely low power supply voltage which has been traditionally unavailable.

It is a technical advantage of the present invention to provide an improved level shifter circuit which is designed to operate with an extremely low power supply voltage.

It is another technical advantage of the present invention to provide an improved level shifter circuit which prevents the breakdown of the gate oxide in all of the transistors.

It is still another technical advantage of the present invention to provide an improved level shifter circuit which includes a secondary path circuit for passing a high voltage to an output terminal when the high voltage is lowered to be equal to a power supply voltage of +1.0 volts.

In a preferred embodiment of the present invention, there is provided a level shifter circuit for use with an extremely low power supply voltage which includes an input terminal for receiving an input signal having first and second levels and an output terminal for providing an output signal having third and fourth levels. There is provided a first power supply voltage having the extremely low power supply voltage, a second power supply voltage having a ground potential, and a third power supply voltage having a high voltage.

There is provided first and second PMOS transistors. The first PMOS transistor has its source connected to the source of the second PMOS transistor, its drain connected to the gate of the second PMOS transistor at an internal node, and its gate connected to the drain of the second PMOS transistor and to the output terminal.

There are provided first and second NMOS transistors. The first NMOS transistor has its drain connected to the drain of the second PMOS transistor and to the output terminal. The first NMOS transistor has its source connected to the drain of the second NMOS transistor and its gate connected to the first power supply voltage. The second NMOS transistor has its gate connected to receive the input signal and its source connected to the ground potential. A third NMOS transistor has its drain connected to the input terminal, its gate connected to the first power supply voltage, and its source connected to the internal node.

A secondary path circuit is responsive to the input signal for transferring the high voltage to the output terminal when the high voltage is lowered to be equal to the first power supply voltage. The secondary path circuit includes a fourth NMOS transistor, a third PMOS transistor, and a fifth NMOS transistor connected in series and interconnected between the high voltage and the output terminal and an inverter.

BRIEF DESCRIPTION OF DRAWINGS

These and other objects and advantages of the present invention will become more fully apparent from the following detailed description when read in conjunction with the accompanying drawings with like reference numerals indicating corresponding parts throughout, wherein:

Figure 1 is a schematic circuit diagram of a prior art level shifter circuit; and

Figure 2 is a schematic circuit diagram of an improved level shifter circuit, constructed in accordance with the principles of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

Referring now to Figure 2 of the drawings, there is shown a schematic circuit diagram of an improved level shifter circuit **110** constructed in accordance with the principles of the present invention.

The level shifter circuit **110** is used to convert logic signals from a core device (e.g., microprocessor) having voltage levels of low and high (0 V and $V_{CC} = +1.0$ V) to higher input/output (I/O) voltage levels of a high voltage **HV** (e.g., $V_{CC} = +10$ V) and 0 V. The inverting level shifter **110** represents an improvement over the level shifter **10** of

Figure 1 which is still functional at the extremely low power supply potential of +1.0 volts.

The level shifter circuit **110** is comprised of a pass N-channel MOS transistor **N101**; pull-up P-channel MOS transistors **P101**, **P102**; and
5 pull-down N-channel MOS transistors **N104**, **N105**. In particular, the first P-channel transistor **P101** has its source connected to the source of the second P-channel transistor **P102** and to a high voltage **HV**, which is typically at approximately $V_{CC} - +10$ volts. The drain of the transistor **P101** is connected to the gate of the transistor **P102** at an
10 internal node **B** and to the source of the pass transistor **N101**. The gate of the transistor **P101** is connected to the drain of the transistor **P102** at a node **A1**, which is connected to an output terminal **OUT**.

The pass transistor **N101** has its drain connected to an input terminal **IN** for receiving an input signal and to the gate of the pull-
15 down transistor **N105**. The gate of the transistor **N101** is connected to a first power supply potential **VCC**, which is typically at +1.0 volts. The pull-down transistor **N104** has its drain connected also to the node **A1** and to the output terminal **OUT**. The pull-down transistor **N105** has its drain connected to the source of the transistor **N104** and its source
20 connected to a second power supply or ground potential **VSS** (zero volts). The n-type substrate of the P-channel transistors **P101**, **P102** is tied to its source and to the high voltage **HV**. As thus far described, the elements of Figure 2 and their interconnection are identical to the components in the level shifter circuit **10** of Figure
25 1.

In addition to these elements, the level shifter circuit **110** of the present invention further includes a secondary path circuit formed by pass N-channel MOS transistors **N102**, **N103**; pass P-channel MOS transistor **P103**; and a CMOS inverter **INV**. The NMOS transistor **N102** has
30 its drain also connected to the source of the transistor **P101** to receive the high voltage **HV** and its source connected to the source of the PMOS transistor **P103**. The NMOS transistor **N103** has its drain connected to the drain of the PMOS transistor **P103** and its source connected also to the node **A1**. The gate of the transistor **P103** is
35 connected to the drain of the transistor **N101** and receives the input signal **IN**. The gates of the transistors **N102** and **N103** are connected together and to the output of the inverter **INV**. The input of the inverter **INV** is connected also to the drain of the transistor **N101** and

receives the input signal **IN**. The CMOS inverter **INV** is a conventional inverter and is formed of a P-channel transistor and an N-channel transistor whose gates are connected together defining its input and whose drains are connected together defining its output.

5 Unlike the prior art of Figure 1, the level shifter circuit **110** of the present invention has a second pull-up path through the transistors **N102**, **P103** and **N103** instead of a single pull-up path through the transistor **P2** of Figure 1. Since the high voltage **HV** is approximately $V_{CC} - +10$ volts, the transistors **N102**, **N103** are made of a
10 thicker gate oxide so as to be able to withstand a drain-to-gate voltage of +10 V. Further, the transistors **N102**, **N103** are depletion-type transistors whose values of the threshold voltage V_{tn} , including the body effect, are equal to approximately 0 volts.

The transistor **P103** is made of a thinner gate oxide (e.g., 60 Å)
15 so as to have a lower threshold voltage in order to be operational, but will not be capable of handling the high voltage **HV** due to the oxide breakdown. Thus, the transistor **P103** is sandwiched or connected in series between the NMOS transistors **N102**, **N103** which function to protect the gate oxide of the transistor **P103** under the situation when
20 the high voltage **HV** exceeds the first (low) power supply potential **VCC**.

The absolute value of the threshold voltage V_{tp} , including the body effect, is equal to approximately one-half of the first power supply potential **VCC**.

The operation of the level shifter circuit **110** will now be
25 explained for the condition when the first (low) power supply potential **VCC** is equal to +1.0 V and the high voltage **HV** is equal to the first (low) power supply voltage. When the input signal at the input terminal **IN** is high or at **VCC**, the pull-down transistor **N105** will be turned ON so as to pull the node **A1** to the ground potential. Thus, the
30 voltage level will be 0 volts at the output terminal **OUT**. It will be noted that only the transistor **P102** will be turned OFF since the transistors **N102** and **N103** are of the depletion-type .

When the input signal **IN** switches from **VCC** to 0 V, the transistor **N105** will be turned OFF and all of the transistors **N102**, **P103**, **N103**
35 will be turned ON. As a result, the high voltage **HV** will be passed via these transistors to the node **A1** and the voltage of **HV** (**VCC**) will be produced at the output terminal **OUT**.

From the foregoing detailed description, it can thus be seen that

the present invention provides an improved level shifter circuit which includes a second pull-up path for transferring or connecting the high voltage to the output terminal when the high voltage is lowered to be equal to the power supply voltage. The level shifter circuit of the present invention includes a secondary path circuit formed of a fourth NMOS transistor, a third PMOS transistor, and a fifth NMOS transistor connected in series and interconnected between the high voltage and the output terminal. As a result, the level shifter circuit will still operate when the power supply voltage **VCC** is reduced down to an extremely low power supply voltage of +1.0 volts.

While there has been illustrated and described what is at present considered to be a preferred embodiment of the present invention, it will be understood by those skilled in the art that various changes and modifications may be made, and equivalents may be substituted for elements thereof without departing from the true scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the central scope thereof. Therefore, it is intended that this invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out the invention, but that the invention will include all embodiments falling within the scope of the appended claims.

CLAIMS

1. A level shifter circuit for use with an extremely low power supply voltage, said level shifter circuit comprising:

an input terminal (**IN**) for receiving an input signal having first
5 and second levels;

an output terminal (**OUT**) for providing an output signal having third and fourth levels;

a first power supply voltage (**VCC**) having the extremely low power supply voltage;

10 a second power supply voltage (**VSS**) having a ground potential;

a third power supply voltage (**HV**) having a high voltage;

first and second PMOS transistors (**P101**, **P102**), said first PMOS transistor having its source connected to the source of said second PMOS transistor, its drain connected to the gate of said second PMOS
15 transistor at an internal node, and its gate connected to the drain of said second PMOS transistor and to said output terminal;

first and second NMOS transistors (**N104**, **N105**), said first NMOS transistor having its drain connected to the drain of said second PMOS transistor and to said output terminal, said first NMOS transistor
20 having its source connected to the drain of said second NMOS transistor and its gate connected to the first power supply voltage, said second NMOS transistor having its gate connected to receive said input signal and its source connected to the ground potential;

a third NMOS transistor (**N101**) having its drain connected to said
25 input terminal, its gate connected to said first power supply potential, and its source connected to the internal node; and

means responsive to said input signal for passing said high voltage to said output terminal when said high voltage is lowered to be equal to said first power supply voltage.

30 2. A level shifter circuit as claimed in Claim 1, wherein said first low power supply voltage is approximately +1.0 volts.

3. A level shifter circuit as claimed in Claim 2, wherein said high voltage is approximately +8 - +10 volts.

4. A level shifter circuit as claimed in Claim 3, wherein said
35 first and second levels are respective voltage levels of zero volts and the low power supply voltage.

5. A level shifter circuit as claimed in Claim 4, wherein said third and fourth levels are respective voltages of the high voltage and

zero volts.

6. A level shifter circuit as claimed in Claim 1, wherein said passing means includes a fourth NMOS transistor (**N102**), a third PMOS transistor (**P103**), and a fifth NMOS transistor (**N103**) connected in series and interconnected between said high voltage and said output terminal, and an inverter (**INV**).

7. A level shifter circuit as claimed in Claim 6, wherein said fourth NMOS transistor has its drain connected to said high voltage, its source connected to the source of said third PMOS transistor, and its gate connected to the output of said inverter, said third PMOS transistor having its drain connected to the drain of said fifth NMOS transistor and its gate connected to said input terminal, said fifth NMOS transistor having its source connected to said output terminal and its gate connected to the gate of said fourth NMOS transistor, said inverter having its input connected to said input terminal.

8. A level shifter circuit as claimed in Claim 5, wherein said passing means includes a fourth NMOS transistor (**N102**), a third PMOS transistor (**P103**), and a fifth NMOS transistor (**N103**) connected in series and interconnected between said high voltage and said output terminal, and an inverter (**INV**).

9. A level shifter circuit as claimed in Claim 8, wherein said fourth NMOS transistor has its drain connected to said high voltage, its source connected to the source of said third PMOS transistor, and its gate connected to the output of said inverter, said third PMOS transistor having its drain connected to the drain of said fifth NMOS transistor and its gate connected to said input terminal, said fifth NMOS transistor having its source connected to said output terminal and its gate connected to the gate of said fourth NMOS transistor, said inverter having its input connected to said input terminal.

10. A level shifter circuit as claimed in Claim 9, wherein said fourth and fifth NMOS transistors are depletion-type transistors.