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10 LOW-TO-HIGH VOLTAGE CMOS DRIVER CIRCUIT FOR
 DRIVING CAPACITIVE LOADS

15 This invention relates to high speed, low-to-high
voltage CMOS driver circuits for driving capacity loads.

20 Semiconductor integrated circuits employ output driver
circuits to drive capacitive loads. One example use of an
output driver circuit is to drive row select lines in a
semiconductor memory array.

25 Conventional output driver circuits utilize
complementary metal-on-semiconductor (CMOS) technology. A
conventional CMOS output circuit includes a p-channel MOS
(PMOS) transistor coupled between voltage and an output
node, and an n-channel MOS (NMOS) transistor coupled
between the output node and ground. The CMOS design
30 enables the PMOS transistor to be "on" while the NMOS
transistor is "off", and vice versa, in response to a
single input signal. When the PMOS transistor is "on" and
the NMOS transistor is "off", the CMOS driver circuit
outputs a voltage. Conversely, when the PMOS transistor is
35 "off" and the NMOS transistor is "on", the output of the
CMOS driver circuit is grounded.

One drawback inherent in the design of conventional
CMOS output driver circuits is that during the rail-to-rail

voltage swing at the input, there exists a period of time when both the PMOS and NMOS transistors are "on". This dual activation condition causes a phenomenon known as "crossing current" which wastes power.

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This invention provides a high speed, low-to-high voltage CMOS driver circuit which eliminates or substantially reduces crossing current in an effort to conserve power.

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Preferred embodiments of the invention are described below with reference to the following accompanying drawings.

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Fig. 1 is a schematic of a low-to-high CMOS driver circuit according to a first preferred embodiment of this invention. The CMOS driver circuit comprises a CMOS output stage, an input stage, and an intermediate voltage translation stage.

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Fig. 2 is a timing diagram illustrating the signals input to, and output from, the CMOS output stage of the CMOS driver circuit of Fig. 1.

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Fig. 3 is a timing diagram of signals generated by the input stage and used to control the intermediate voltage translation stage of the CMOS driver circuit of Fig. 1.

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Fig. 4 illustrates current spikes generated during transition between low voltage output and high voltage output of the CMOS driver circuit in Fig. 1.

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Fig. 5 is a schematic of a low-to-high voltage CMOS driver circuit according to a second embodiment of this invention.

Fig. 6 is a schematic of a low-to-high voltage CMOS driver circuit according to a third embodiment of this invention.

5 Fig. 7 is a schematic of a low-to-high voltage CMOS driver circuit according to a fourth embodiment of this invention.

10 This disclosure of the invention is submitted in furtherance of the constitutional purposes of the U.S. Patent Laws "to promote the progress of science and useful arts". U.S. Constitution, Article 1, Section 8.

15 This invention concerns a high speed CMOS device for driving a capacitive load. The CMOS device includes a CMOS output stage having an NMOS transistor and a PMOS transistor coupled between a first voltage level, such as ground, and a second voltage level, such as Vccp. The CMOS output stage provides an output signal that swings between
20 the first and second voltage levels depending upon whether the NMOS and PMOS transistors are "on" or "off".

25 The CMOS device further includes an output stage control means for receiving an input signal indicative of a desired output signal. The output stage control means generates first and second independent control signals which are used to selectively activate the transistors in the CMOS output stage. That is, the first independent control signal is coupled to turn "on" and "off" the NMOS
30 transistor, and the second independent control signal is coupled to turn "on" and "off" the PMOS transistor. The output stage control means turns "off" the presently activated transistor before turning "on" the presently inactive transistor. In this manner, the output stage
35 control means independently activates the NMOS and PMOS transistors in a time-staggered manner to minimize crossing

current in the CMOS output stage. This in turn saves power which would otherwise be lost due to crossing current.

Fig. 1 shows a high speed, low-to-high voltage CMOS driver circuit 10 according to a most preferred embodiment of this invention. CMOS driver circuit 10 is designed to drive a capacitive load. One example capacitive load is a global row select line in a semiconductor memory array. CMOS driver circuit 10 translates a low voltage input signal RSEL which swings between Vcc (e.g., 2.5 volts) and ground to a high voltage output signal XRSEL that swings between Vccp (e.g., 4.0 volts) and ground. The notation "RSEL" denotes "row select" in keeping with the example of driving a global row select line in a semiconductor memory device. The notation "XRSEL" denotes a voltage translated version of the RSEL signal. The notation "Vccp" is customary to denote a higher voltage or pumped-up level above Vcc.

CMOS driver circuit 10 includes a CMOS output stage 12, an input stage 14, and a low crossing current intermediate voltage translation stage 16 coupled between the input and output stages. CMOS driver circuit 10 also has a driver input 18 which receives the low voltage input signal RSEL and a driver output 20 which outputs the high voltage output signal XRSEL.

CMOS output stage 12 has a first NMOS transistor M2 which has a source-to-drain path coupled between driver output 20 and a first voltage level or ground. CMOS output stage 12 also has a first PMOS transistor M1 which has a source-to-drain path coupled between a second voltage level, or Vccp, and driver output 20. The two transistors in the CMOS output stage 12 are controlled by two independent control signals G1 and G2. When the PMOS transistor M1 is "on" and the NMOS transistor M2 is "off",

the output signal on driver output 20 is at Vccp. Conversely, when the PMOS transistor M1 is "off" and the NMOS transistor M2 is "on", the output signal XRSEL at driver output 20 is at ground. In this manner, the output
5 signal XRSEL swings between Vccp and ground.

Input stage 14 is coupled to driver input 18 and receives input signal RSEL which swings between ground and a third voltage level, or Vcc. Input stage 14 generates at
10 least two, and preferably three, independent control signals based upon input signal RSEL. In the Fig. 1 embodiment, input stage 14 generates a first control signal G1, a second control signal H1, and a third control signal H2. The first control signal G1 is input directly to
15 output stage 12 to control the gate, and thereby activate or deactivate, the NMOS transistor M2. The remaining two control signals H1 and H2 are input to intermediate voltage translation stage 16, as described below in more detail.

20 Input stage 14 includes a latch 22 which generates control signals G1 and H1. Latch 22 is preferably configured as a cross-coupled NOR gate latch having NOR gates 24 and 26. Input stage 14 also includes an inverter 28 to initially invert input signal RSEL and a second
25 inverter 30 coupled between the first inverter and the input of NOR gate 26.

Intermediate voltage translation stage 16 is coupled between input stage 14 and output stage 12. The voltage
30 translation stage receives two internal control signals H1 and H2 from the input stage, and uses these control signals to generate an independent, higher voltage activation control signal G2. This control signal G2 is utilized to control the PMOS transistor M1 of output stage 12. Due to
35 the inherent delay time that it takes input signal RSEL to propagate through input stage 14 and intermediate voltage

translation stage 16, the control signal G2 is time staggered from control signal G1. As a result, control signals G1 and G2 independently turn "on" and "off" the CMOS transistors of output stage 12. This independent
5 control minimizes or eliminates crossing current in the CMOS output stage.

Intermediate voltage translation stage 16 includes a pair of cross-coupled PMOS transistors M5 and M6. A first
10 PMOS transistor M5 has a source-to-drain path coupled between Vccp and a first node H3. The second PMOS transistor M6 has a source-to-drain path coupled between Vccp and an output node G2 which is coupled to the gate of PMOS transistor M1 in output stage 12. The gate of second
15 PMOS transistor M6 is coupled to node H3 and the gate of first PMOS transistor M5 is coupled to output node G2 to form the cross-coupled PMOS transistor structure.

Intermediate voltage translation stage 16 also
20 includes a first NMOS control transistor M3 which has a source-to-drain path coupled between node H3 and ground. The gate of control transistor M3 is coupled to receive the third internal control signal H2 from input stage 14. A second NMOS control transistor M4 has a source-to-drain
25 path coupled between output node G2 and ground. The gate of this second control transistor M4 is coupled to receive the second internal control signal H1 from input stage 14.

Control transistors M3 and M4 control the pair of
30 cross-coupled PMOS transistors M5 and M6 to alternately output at output node G2 an internal control signal that swings between Vccp and ground. Internal signals G2 and H2 selectively turn "on" and "off" control transistors M3 and M4 in an alternating, out-of-phase fashion. When control
35 transistor M3 is "on" and control transistor M4 is "off", first node H3 is grounded, thereby turning "on" PMOS

transistor M6. The Vccp voltage is thus placed at output node G2, keeping PMOS transistor M5 in an "off" state.

5 When control transistor M4 is "on" and control transistor M3 is "off", output node G2 is grounded and first PMOS transistor M5 is turned "on". Second PMOS transistor M6 is turned "off". Intermediate stage 16 outputs a ground level voltage at output node G2.

10 According to another aspect of this invention, intermediate voltage translation circuit 16 includes NMOS precharge transistors M7 and M8. A first NMOS precharge transistor M7 which has a gate coupled to the gate of second NMOS control transistor M4 and to input stage 14.
15 Precharge transistor M7 is selectively activated by second internal control signal H1. Precharge transistor M7 has a source-to-drain path coupled between Vcc and first node H3. Similarly, a second NMOS precharge transistor M8 has a gate coupled to the gate of first NMOS control transistor M3 and
20 to input stage 14. Precharge transistor M8 is selectively activated by third internal control signal H2. Precharge transistor M8 has a source-to-drain path coupled between Vcc and output node G2.

25 The precharge transistors M7 and M8 raise respective nodes H3 and G2 toward Vcc before the cross-coupled PMOS transistors M5 and M6 turn "on" to further increase the voltage levels at those nodes to Vccp. For example, when internal control signal H1 goes high to turn "on" control
30 transistor M4, it simultaneously turns "on" precharge transistor M7. As a result, first node H3 begins to rise from ground towards Vcc. Within a minor time delay, PMOS transistor M5 is turned "on" to further raise the voltage level at first node H3 to Vccp. The precharge transistor M8
35 does essentially the same function for output node G2. These precharge transistors help minimize crossing current

through intermediate voltage translation stage 16 during transition.

Precharge transistors M7 and M8 form one
5 implementation of a precharge means for precharging the
pair of cross-coupled transistors M5 and M6 to facilitate
transition during toggle between the two output states.
Other gate arrangements besides the single NMOS transistors
shown can also be used to precharge the respective nodes.
10 Example alternatives might include PMOS transistors, pass
circuits having a combination PMOS and NMOS transistors, or
other equivalent structures.

Fig. 2 illustrates a timing diagram of the independent
15 control signals G1 and G2 used to activate respective
transistors M2 and M1 in CMOS output stage 12. The timing
diagram shows a first transition of output signal XRSEL
from ground to Vccp (e.g., 4.0 volts) and a second
transition from Vccp back to ground. During the first
20 transition, independent control signal G1 goes low to first
turn "off" NMOS transistor M2. Subsequently, the second
independent control signal G2 goes low to turn "on" PMOS
transistor M1. Due to the time-staggered nature of these
two signals, output stage 12 experiences little or no
25 crossing current during the transition. Accordingly, the
operation conserves power by avoiding the crossing current.

During the second transition, second independent
control signal G2 returns high to first turn "off" PMOS
30 transistor M1. Subsequently, first independent control
signal G1 returns high to thereby turn "on" NMOS transistor
M2. Again, the time-staggered nature of these two
independent control signals prevents crossing current
during the transition.

Fig. 3 illustrates the timing diagram of the internal control signals G1, H1, and H2. It is noted that independent control signal G1 follows internal control signal H2 with a slight lag caused by propagation delay through two semiconductor gates. Internal control signal H1 is inversely out-of-phase with control signals G1 and H2. With H1 and H2 out-of-phase, control transistors M3 and M4 are alternately "on" and "off". Fig. 3 also shows the voltage at first node H3 which swings from ground to Vccp (e.g., 4.0 volts).

Fig. 4 shows the load current spikes measured at output stage 12 which occur during the transitions shown in Figs. 2 and 3. These load current spikes represent the current flowing through either PMOS transistor M1 or NMOS transistor M2 into a capacitive load. If no crossing current existed, current spikes 41 and 43 would be eliminated. It is noted that the second current spike 42 has a slightly larger amplitude than the first current spike 40, indicating that the output stage did experience slightly higher crossing current on the high to low transition. However, the circuit design of this invention effectively minimizes such conditions.

It is further noted that the CMOS driver circuit 10 minimizes crossing current in the intermediate voltage translation stage 16. Accordingly, the circuit effectively eliminates or substantially reduces crossing current in both the output stage 12 and the intermediate stage 16.

Fig. 5 illustrates a low-to-high voltage CMOS driver circuit 50 according to a second embodiment of this invention. CMOS driver circuit 50 includes output stage 12, intermediate voltage translation stage 16, and an input stage 52. CMOS driver circuit 50 differs from CMOS driver circuit 10 of Fig. 1 in that input stage 52 includes a

cross-coupled NAND gate latch 54 having a first NAND gate 56 and a second NAND gate 58. Input stage 52 further includes inverters 60 and 62 on the front end of NAND gate latch 54, and inverters 64 and 66 on the back end of the NAND gate latch. According to this construction, input stage 52 outputs three different control signals A, B, and C.

NAND gate latch 52 of driver circuit 50 in Fig. 5 substantially reduces crossing current in intermediate stage 16 and output stage 12, but not quite to the same extent as the NOR gate latch in driver circuit 10 of Fig. 1. Accordingly, the Fig. 5 embodiment is slightly less preferred than the embodiment of Fig. 1.

Fig. 6 illustrates a low-to-high voltage CMOS driver circuit 70 according to a third embodiment of this invention. The CMOS driver circuit 70 differs from the circuits of Figs. 1 and 5 in that the intermediate and output stages are combined. That is, the same PMOS transistor M1 functions as an output transistor in the output stage as well as one of the cross-coupled transistors in the intermediate stage. Additionally, the NMOS transistor M2 has a dual function of an output transistor in the output stage and as a control transistor for the intermediate stage.

More specifically, CMOS driver circuit 70 includes a driver input 72, a driver output 74, an output stage 76, an input stage 78, and an intermediate voltage translation stage 80. A first PMOS transistor M1 has a source-to-drain path coupled between Vccp and driver output 74. The gate of PMOS transistor M1 defines a first node 82. A first NMOS transistor M2 has a source-to-drain path coupled between driver output 74 and ground. The gate of NMOS transistor M2 is coupled to input stage 78. A second PMOS

transistor M3 has a source-to-drain path coupled between Vccp and first node 82. A second NMOS transistor M4 has a source-to-drain path coupled between first node 82 and ground.

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PMOS transistor M1 and NMOS transistor M2 define output stage 76. Additionally, transistors M1-M4 define intermediate voltage translation stage 80. Accordingly, transistors M1 and M2 have dual roles in this circuit.

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Input stage 78 generates two mutually exclusive signals D and E which are coupled to operate NMOS transistors M2 and M4. Input stage 78 comprises a first inverter 84 coupled between driver input 72 and a second node 86, and a second inverter 88 coupled between second node 86 and the gate of NMOS transistor M2. Second node 86 is tied to the gate of NMOS transistor M4.

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In the Fig. 6 embodiment, intermediate voltage translation stage 80 also includes a third NMOS transistor M5 and a fourth NMOS transistor M6. Transistors M5 and M6 have source-to-drain paths coupled in series between Vcc and first node 82. The gate of third transistor M5 is coupled to driver input 72 and the gate of fourth transistor M6 is coupled to Vccp. Transistors M5 and M6 act to precharge node 82 in an effort to facilitate toggle transition of the cross-coupled PMOS transistors M1 and M3, in a manner similar to that described above with respect to Fig. 1.

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Fig. 7 illustrates a low-to-high voltage CMOS driver circuit 90 according to a fourth embodiment of this invention. Driver circuit 90 is similar to circuit 70 of Fig. 6, but has a slightly different construction in the intermediate voltage translation stage 92 and the input

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stage 94. Only the differences in this circuit as compared to the circuit of Fig. 6 will be described in detail.

Intermediate voltage translation stage 92 includes a fifth NMOS transistor M7 and sixth NMOS transistor M8. Transistors M7 and M8 have source-to-drain paths coupled in series between Vcc and driver output 74. Fifth transistor M7 has a gate tied to the gate of transistor M4 and to node 86. The gate of sixth transistor M8 is coupled to Vccp. Transistors M7 and M8 function to precharge the cross-coupled PMOS transistors of intermediate voltage translation stage 92 by preliminarily bringing the voltage at the driver output node 74 to Vcc.

Input stage 94 has a NOR gate 96 coupled between driver input 72 and second node 86, and inverter 88. NOR gate 96 has a second input coupled to receive a second control signal CSG.

The high speed, low-to-high voltage CMOS driver circuits of this invention are advantageous over prior art output driver circuits in that the output stage is driven by independent control signals which turn "off" the activated transistor before turning "on" the inactive transistor. In this manner, crossing current within the output stage is minimized or eliminated. The circuit therefore conserves power by avoiding cross-current during signal swings.

In compliance with the statute, the invention has been described in language more or less specific as to structural and methodical features. It is to be understood, however, that the invention is not limited to the specific features shown and described, since the means herein disclosed comprise preferred forms of putting the invention into effect. The invention is, therefore,

claimed in any of its forms or modifications within the proper scope of the appended claims appropriately interpreted in accordance with the doctrine of equivalents.



CLAIMS:

1. A CMOS driver circuit for driving a capacitive load, comprising:

- 5 a CMOS output stage having a PMOS transistor and an NMOS transistor coupled between first and second voltage levels, the CMOS output stage providing an output signal that swings between the first and second voltage levels;
- 10 an input stage coupled to receive an input signal that swings between the first voltage level and a third voltage level that is less than the second voltage level, the input stage generating at least first and second independent control
- 15 signals based upon the input signal, the first control signal being used to activate one transistor of the CMOS output stage; and
- an intermediate voltage translation stage coupled between the input and output stages, the voltage
- 20 translation stage receiving the second control signal from the input stage and using the second control signal to generate an activation signal at the second voltage level, the activation signal activating the other transistor of the
- 25 CMOS output stage at a different time than the input stage activates the one transistor of the CMOS output stage to thereby minimize crossing current in the CMOS output stage.



2. The CMOS driver circuit of claim 1 wherein:
the input stage is coupled to activate the NMOS
transistor in the CMOS output stage; and
the intermediate voltage translation stage is coupled
5 to activate the PMOS transistor in the CMOS
output stage.

3. The CMOS driver circuit of claim 1 wherein the
input stage includes a latch to generate the first and
10 second control signals.

4. The CMOS driver circuit of claim 1 wherein the
input stage includes a cross-coupled NOR gate latch to
generate the first and second control signals.

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5. The CMOS driver circuit of claim 1 wherein the
input stage includes a cross-coupled NAND gate latch to
generate the first and second control signals.

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6. The CMOS driver circuit of claim 1 wherein the
input stage includes serially connected inverters which
generate the first and second control signals.

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7. The CMOS driver circuit of claim 1 wherein:
the input stage generates a third control signal; and
the intermediate voltage translation stage includes a
pair of cross-coupled transistors which are



operable controlled by the second and third control signals from the input stage.

8. The CMOS driver circuit of claim 1 wherein the
5 intermediate voltage translation stage comprises:

a pair of cross-coupled transistors having inversely related output states;

first and second control transistors connected to the pair of cross-coupled transistors to toggle the
10 output states; and

precharge means for precharging the pair of cross-coupled transistors to facilitate transition during toggle between the output states.

15 9. The CMOS driver circuit of claim 1 wherein the intermediate voltage translation stage includes a pair of cross-coupled PMOS transistors, the intermediate voltage translation stage being coupled to activate the PMOS transistor in the CMOS output stage.

20 10. The CMOS driver circuit of claim 9 wherein the PMOS transistor in the CMOS output stage is one of the transistors in the pair of cross-coupled PMOS transistors.

25 11. A low-to-high voltage CMOS driver circuit for driving a capacitive load, the CMOS driver circuit translating a low voltage input signal that swings between



Vcc and ground to a high voltage output signal that swings between Vccp and ground, where $V_{ccp} > V_{cc}$; the CMOS driver circuit comprising:

5 a driver input which receives the low voltage input signal;

a driver output which outputs the high voltage output signal;

10 a CMOS output stage having a PMOS transistor and an NMOS transistor, the PMOS transistor having a gate and a source-to-drain path coupled between Vccp and the driver output, the NMOS transistor having a gate and a source-to-drain path coupled between the driver output and ground;

15 an input stage coupled to the driver input and having first, second, and third outputs, the input stage generating three different signals and outputting them over the three outputs, the first output of the input stage being connected to the gate of the NMOS transistor in the output stage; and

20 an intermediate voltage translation stage coupled between the input and output stages, the intermediate voltage translation stage comprising:

25 a pair of first and second cross-coupled PMOS transistors, the first PMOS transistor having a gate and a source-to-drain coupled between Vccp and a first node, the second



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PMOS transistor having a gate and a source-to-drain path coupled between Vccp and an output node, the gate of the second PMOS transistor being coupled to the first node and the gate of the first PMOS transistor being coupled to the output node to form the cross-coupled PMOS transistor structure, the output node being coupled to the gate of the PMOS transistor in the output stage;

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a first NMOS control transistor having a gate coupled to the third output of the input stage and a source-to-drain path coupled between the first node and ground; and

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a second NMOS control transistor having a gate coupled to the second output of the input stage and a source-to-drain coupled between the output node and ground.

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12. A low-to-high voltage CMOS driver circuit according to claim 11 wherein the intermediate voltage translation stage further comprises:

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a first NMOS precharge transistor having a gate coupled to the second NMOS control transistor and a source-to-drain path coupled between Vcc and the first node; and

a second NMOS precharge transistor having a gate coupled to the first NMOS control transistor and



a source-to-drain path coupled between V_{cc} and the output node.

13. A low-to-high voltage CMOS driver circuit for driving a capacitive load, the CMOS driver circuit translating a low voltage input signal that swings between V_{cc} and ground to a high voltage output signal that swings between V_{ccp} and ground, where $V_{ccp} > V_{cc}$; the CMOS driver circuit comprising:
- 10 a driver input which receives the low voltage input signal;
 - a driver output which outputs the high voltage output signal;
 - a first PMOS transistor having a gate and a source-to-drain path coupled between V_{ccp} and the driver output, the gate defining a first node;
 - 15 a first NMOS transistor having a gate and a source-to-drain path coupled between the driver output and ground;
 - 20 a second PMOS transistor having a gate coupled to the driver output and a source-to-drain path coupled between V_{ccp} and the first node;
 - a second NMOS transistor having a gate and a source-to-drain path coupled between the first node and ground; and
 - 25 an input stage coupled to the driver input and having first and second outputs coupled to respective



gates of the first and second NMOS transistors,
the input stage generating two mutually exclusive
signals and outputting the signals on the first
and second outputs.

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14. A low-to-high voltage CMOS driver circuit
according to claim 13 wherein the input stage includes:

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a first inverter coupled between the driver input and
a second node, the second node being coupled to
the gate of the second NMOS transistor; and
a second inverter coupled between the second node and
the gate of the first NMOS transistor.

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15. A low-to-high voltage CMOS driver circuit
according to claim 13 wherein the input stage includes:

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a NOR gate between the driver input and a second node,
the second node being coupled to the gate of the
second NMOS transistor; and
an inverter coupled between the second node and the
gate of the first NMOS transistor.

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16. A low-to-high voltage CMOS driver circuit
according to claim 13 further comprising:

third and fourth NMOS transistors having respective
gates and source-to-drain paths coupled in series
between Vcc and the first node, the gate of the
third NMOS transistor being coupled to the driver



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input and the gate of the fourth NMOS transistor
being coupled to Vccp.

17. A low-to-high voltage CMOS driver circuit
5 according to claim 13 further comprising:

third and fourth NMOS transistors having respective
gates and source-to-drain paths coupled in series
between Vcc and the first node, the gate of the
third NMOS transistor being coupled to the driver
10 input and the gate of the fourth NMOS transistor
being coupled to Vccp; and

fifth and sixth NMOS transistors having respective
gates and source-to-drain paths coupled in series
between Vcc and the driver output, the gate of
15 the fifth NMOS transistor being coupled to the
first output of the input stage and the gate of
the sixth NMOS transistor being coupled to Vccp.

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