

# **A FILTERED RADIATION HARDENED FLIP FLOP WITH REDUCED POWER CONSUMPTION**

## **BACKGROUND**

**[0001]** Embodiments of this disclosure relate generally to electronic circuits, and more particularly, to a filtered low power, radiation hardened flip-flop circuit that mitigates sensitivity to single event upsets and single event transients (SETs).

**[0002]** Flip-flops may be used in logic pipelines in high performance digital Application Specific Integrated Circuits (ASIC), and mixed-signal Systems-on-Chip (SOC). As technologies scale, power density generally increases, making it necessary to develop new logic circuits that use less power. This trend is even more evident in ASICs and SOCs designed for space applications, where the spatial and temporal redundancy techniques used to mitigate Single Event Effects (SEE) caused by energetic particles may exacerbate power density concerns.

**[0003]** A single event in a flip-flop can flip the stored data, causing a Single Event Upset (SEU). Single events in logic gates create Single Event Transients (SETs) that can be captured by a flip-flop.

**[0004]** Spatial redundancy may be used to mitigate SEUs in

flip-flops. Spatial redundancy is where two or more copies of the flip-flops may be used to reduce susceptibility to upsets in the flip flops. Transient filters may further be used to reduce or eliminate transients generated in the logic preceding the flip-flop and to keep the transients from being captured by the flip-flop. The addition of one or more redundant flip-flops and transient filters generally increases power and reduces performance significantly. The impact of redundancy depends on the flip-flop topology, while the impact of transient filters is similar for all flip-flop topologies.

**[0005]** A Dual Interlocked Storage Cell (DICE) flip flop with transient filters may be used to remove SETs at the flip-flop inputs. DICE flip flops have improved SEU tolerance by interlocking the storage nodes of two flip-flops. However, DICE flip flops generally use at least twice as much power as an unhardened flip-flop.

**[0006]** A Triple Modular Redundancy (TMR) flip flop also has improved SEU tolerance by triplicating the flip flop and using a majority voter to select the correct result. However, TMR flip flops generally use more than 3 times the power of the unhardened flip-flop.

**[0007]** Resistor-Capacitor (RC) filters may be used to mitigate SEUs in flip-flops. However, the resistors and capacitors generally require very large area in modern process

technologies.

[0008] Therefore, it would be desirable to provide a system and method that overcomes the above identified problems, and others.

#### **SUMMARY**

[0009] According to an embodiment, a flip flop circuit has a first stage and a second stage. The first stage and the second stage each have interleaved filters. The interleaved filter of the first stage comprises: a first stage delay circuit; and a first stage output buffer having a first input coupled to an input of the flip flop circuit and a second input coupled to an output of the first stage delay circuit. The first stage delay circuit has a selectable delay programmable through an input clock signal

[0010] According to another embodiment, a flip flop circuit has a first stage. The first stage has a first stage interleaved filter having a first stage interleaved filter input and a first stage interleaved filter output; and a first stage feedback inverter coupled to the first stage interleaved filter input and to the first stage interleaved filter output. The flip flop circuit has a second stage. The second stage has a second stage interleaved filter having a second stage

interleaved filter input and a second stage interleaved filter output; and a second stage feedback inverter coupled to the second stage interleaved filter input and to the second stage interleaved filter output. A switching device is coupled between the first stage and the second stage. The first stage interleaved filter comprises: a first stage delay circuit, wherein the first stage delay circuit is a selectable delay programmable through an input clock signal; and a first stage output buffer coupled to the first stage delay circuit, wherein the first stage output buffer comprises a plurality of transistors, wherein the plurality of transistors are interleaved.

[0011] According to yet another embodiment, a multi-stage flip flop circuit has a first stage interleaved filter coupled to an input of the multi-stage flip flop. A first stage feedback inverter is coupled to the input of the multi-stage flip flop and to a first stage interleaved filter output. A

second stage interleaved filter is coupled to the first stage interleaved filter output. A second stage feedback inverter is coupled to the first stage interleaved filter output and to a second stage interleaved filter output. A switching device is coupled between the first stage and the second stage.

The first stage interleaved filter has a delay circuit and the second stage interleaved filter has a selectable delay circuit having a selectable delay programmable through an input clock signal.

**[0012]** Further, the disclosure comprises embodiments according to the following clauses:

**[0013]** Clause 1. A flip flop circuit, comprising: a first stage; and a second stage, wherein the first stage and the second stage each have interleaved filters.

**[0014]** Clause 2. The flip flop circuit in accordance with Clause 1, wherein the interleaved filter of the first stage comprises: a first stage delay circuit; and a first stage output buffer having a first input coupled to an input of the flip flop circuit and a second input coupled to an output of the first stage delay circuit.

**[0015]** Clause 3. The flip flop circuit in accordance with Clause 2, further comprising a first stage feedback inverter coupled between an output of the first stage output buffer and

the input of the flip flop.

**[0016]** Clause 4. The flip flop circuit in accordance with Clause 2, wherein the first stage delay circuit has a fixed delay.

**[0017]** Clause 5. The flip flop circuit in accordance with

Clause 2, wherein the first stage delay circuit has a selectable delay.

**[0018]** Clause 6. The flip flop circuit in accordance with Clause 1, wherein the interleaved filter of the second stage comprises: a second stage delay circuit; and a second stage output buffer having a first input coupled to an input of the second stage and a second input coupled to an output of the second stage delay circuit.

**[0019]** Clause 7. The flip flop circuit in accordance with Clause 6, further comprising a second stage feedback inverter coupled between an output of the second stage output buffer and the input of the second stage.

**[0020]** Clause 8. The flip flop circuit in accordance with Clause 6, wherein the second stage delay circuit has a fixed delay.

**[0021]** Clause 9. The flip flop circuit in accordance with Clause 6, wherein the second stage delay circuit has a selectable delay.

**[0022]** Clause 10. A flip flop circuit comprising: a first stage comprising: a first stage interleaved filter having a first stage interleaved filter input and a first stage interleaved filter output; and a first stage feedback inverter coupled to the first stage interleaved filter input and to the first stage interleaved filter output; a second stage

comprising: a second stage interleaved filter having a second stage interleaved filter input and a second stage interleaved filter output; and a second stage feedback inverter coupled to the second stage interleaved filter input and to the second stage interleaved filter output; and a switching device coupled between the first stage and the second stage.

**[0023]** Clause 11. The flip flop circuit in accordance with Clause 10, wherein the first stage interleaved filter comprises: a first stage delay circuit; and a first stage output buffer coupled to the first stage delay circuit, wherein the first stage output buffer comprises a plurality of transistors, wherein the plurality of transistors are interleaved.

**[0024]** Clause 12. The flip flop circuit in accordance with Clause 11, wherein the first stage delay circuit has a fixed delay.

**[0025]** Clause 13. The flip flop circuit in accordance with Clause 11, wherein the first stage delay circuit has a selectable delay.

**[0026]** Clause 14. The flip flop circuit in accordance with Clause 10, wherein the second stage interleaved filter comprises: a second stage delay circuit; and a second stage output buffer coupled to the second stage delay circuit, wherein the second stage output buffer comprises a plurality of transistors, wherein the plurality of transistors are

interleaved.

**[0027]** Clause 15. The flip flop circuit in accordance with Clause 14, wherein the second stage delay circuit has a fixed delay.

**[0028]** Clause 16. The flip flop circuit in accordance with Clause 14, wherein the second stage delay circuit has a selectable delay.

**[0029]** Clause 17. A multi-stage flip flop circuit comprising: a first stage interleaved filter coupled to an input of the multi-stage flip flop; a first stage feedback inverter coupled to the input of the multi-stage flip flop and to a first stage interleaved filter output; a second stage interleaved filter coupled to the first stage interleaved filter output; a second stage feedback inverter coupled to the first stage interleaved filter output and to a second stage interleaved filter output; and a switching device coupled between the first stage and the second stage.

**[0030]** Clause 18. The multi-stage flip flop circuit in accordance with Clause 17, wherein the first stage interleaved filter and the second stage interleaved filter each have a fixed delay circuit.

**[0031]** Clause 19. The multi-stage flip flop circuit in accordance with Clause 17, wherein the first stage interleaved filter and the second stage interleaved filter each have a

selectable delay.

[0032] Clause 20. The multi-stage flip flop circuit in accordance with Clause 17, wherein the first stage interleaved filter has a fixed delay circuit and the second stage interleaved filter has a selectable delay circuit.

[0033] The features, functions, and advantages may be achieved independently in various embodiments of the disclosure or may be combined in yet other embodiments.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0034] Embodiments of the disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0035] **Figure 1** is a block diagram of one embodiment of a radiation hardened flip-flop;

[0036] **Figure 2** is a simplified schematic of the radiation hardened flip-flop of **Figure 1**;

[0037] **Figure 3** is a block diagram of another embodiment of a radiation hardened flip-flop;

[0038] **Figure 4** is a simplified schematic of the radiation hardened flip-flop of **Figure 3**;

[0039] **Figure 5** is a block diagram of another embodiment of a radiation hardened flip-flop; and

[0040] **Figure 6** is a simplified schematic of the radiation

hardened flip-flop of **Figure 5**.

#### **DETAILED DESCRIPTION**

[0041] Referring to **Figures 1** and **2**, a logic circuit **10** may be described. In the present embodiment, the logic circuit **10** may be configured as a flip flop **10A**. The flip flop **10A** may be designed to mitigate sensitivity to single event upsets and single event transients (SETs), with lower power consumption than other single event effects-mitigated logic circuits. The flip flop **10A** treats the single event as an internal transient that needs to be filtered before it becomes an upset.

[0042] The flip flop **10A** may have an input buffer **14**. In the present embodiment, the input buffer **14** may be an inverter **14A**. The inverter may be formed of a pair of transistors **16** and **18**. The pair of transistors **16** and **18** may be complementary MOSFETS. As shown, the transistor **16** may be a P-type transistor such as a P-type MOSFET, while the transistor **18** may be an N-type transistor such as an N-type MOSFET. The transistor **16** may be coupled to a voltage supply **VDD**, while the transistor **18** may be coupled to a voltage supply **VSS**.

[0043] A switching device **20** may be coupled to an output of the inverter **14A**. The switching device **20** may be used to pass on the output of the inverter **14A**. In accordance with one embodiment, the switching device **20** may be a pass gate **20A**. The

pass gate **20A** may be used to pass on the logic level output from the inverter **14A** to a first stage **26** of the flip flop **10A**. The pass gate **20A** may be formed of a pair of transistors **22** and **24**. As shown, the transistor **22** may be a P-type transistor such as a P-type MOSFET, while the transistor **24** may be an N-type transistor such as an N-type MOSFET. The transistor **22** may be coupled to a clock signal **CLK**, while the transistor **24** may be coupled to an inverted clock signal **NCLK**.

**[0044]** In the present embodiment, the flip flop **10A** is a multi-stage flip flop having a first stage **26** and a second stage **28**. A switching device **30** may be positioned between an output of the first stage **26** and an input of the second stage **28**. In accordance with one embodiment, the switching device **30** is a pass gate **30A** which may be used to pass the logic level output from the first stage **26** to the input of the second stage **28**. The pass gate **30A** may be formed of a pair of transistors **60** and **62**. As shown, the transistor **60** may be a P-type transistor such as a P-type MOSFET, while the transistor **62** may be an N-type transistor such as an N-type MOSFET. The transistor **62** may be coupled to the clock signal **CLK**, while the transistor **60** may be coupled to the inverted clock signal **NCLK**.

**[0045]** In the present embodiment, the first stage **26** may have a first stage interleaved filter **32**. A first stage feedback inverter **34** may be coupled between the output of the

first stage interleaved filter **32** and the input of the first stage interleaved filter **32**. Similarly, the second stage **28** may have a second stage interleaved filter **36**. A second stage feedback inverter **38** may be coupled between the output of the second stage interleaved filter **36** and the input of the second stage interleaved filter **36**.

[0046] The first stage interleaved filter **32** is configured to cut off transients coming from the logic preceding the flip-flop **10A** when the inverted clock signal **NCLK** on the pass gate **20A** is **ON** (at a high logic level), and any transients generated within the pass gate **20A**, any transients generated within the first stage feedback inverter **34**, and any transients generated within the first stage interleaved filter **32** when the inverted clock signal **NCLK** on the pass gate **20A** is **OFF**. Likewise, the second stage interleaved filter **36** is configured to cut off transients generated within the first stage interleaved filter **32** when the clock signal **CLK** on the pass gate **30A** is **ON**, and any transients generated within the pass gate **30A** used to pass the logic level output from the first stage **26** to the input of the second stage **28**, and any transients generated within the second stage feedback inverter **38**, and any transients generated within the second stage interleaved filter **36** when the clock signal **CLK** on the pass gate **30A** is **OFF**.

[0047] As shown in **Figure 2**, the first stage interleaved

filter **32** may be formed of a first stage delay circuit **40** and a first stage output buffer **42**. In the present embodiment, the first stage delay circuit **40** may be a fixed delay circuit **40A**. The fixed delay circuit **40A** may be comprised of a plurality of series connected transistor delay elements **39** which provide a delay of a fixed duration. The duration of the fixed delay circuit **40A** may be selected during the design phase of an Application Specific Integrated Circuit (ASIC). The delay time may be a function of process, voltage and temperature. For instance, if the ASIC is manufactured in a slow corner the delay may be greater, but commensurate with the type of transients generated by the logic circuits in the ASIC.

[0048] The first stage output buffer **42** may be a C-gate **42A**. In the embodiment shown, the C-gate **42A** may be comprised of two series PMOS transistors **44**, **46** and two series NMOS transistors **48**, **50**. Each input **52A** and **52B** of the C-gate **42A** controls the gate of one PMOS transistor **44** or **46** and one NMOS transistor **48** or **50**. In the embodiment shown, the input **52A** can control the gate of PMOS transistor **44** and the gate of NMOS transistor **50**. The input **52B** can control the gate of PMOS transistor **46** and the gate of NMOS transistor **48**.

[0049] The output of the pass gate **20A** may be sent to input **52A** of the C-gate **42A** and the fixed delay circuit **40A**. The output of the fixed delay circuit **40A** may be sent to the input

**52B** of the C-gate **42A**. When the inputs **52A** and **52B** of the C-gate **42A** match, the C-gate **42A** may act as an inverter. When the inputs **52A** and **52B** of the C-gate **42A** do not match, the C-gate **42A** may not drive its output (high impedance state), and the output of the C-gate **42A** may maintain its current value. The C-gate **42A** is not sensitive to radiation events that affect a single node. However, a radiation event that causes a double-node strike that affects transistors **44** and **46**, or transistors **48** and **50**, may cause an SET at the output of the C-gate **42A**.

[0050] The spacing needed to reduce double-node strikes of the C-gate **42A** to an acceptable level may be attained by interleaving the PMOS transistors **44**, **46** and the NMOS transistors **48**, **50** in the C-gate **42A**. The first stage delay circuit **40** may be placed between the interleaved PMOS transistors **44**, **46**, and between the interleaved NMOS transistors **48**, **50** in the C-gate **42A**, in order to achieve the desired node spacing without any wasted space.

[0051] The second stage interleaved filter **36** may be formed of a second stage delay circuit **41** and a second stage output buffer **43**. In the present embodiment, the second stage delay circuit **41** may be fixed delay circuit **41A**. The fixed delay circuit **41A** may be comprised of a plurality of series connected transistor delay elements **47** which provide a delay of a fixed duration. The duration of the fixed delay circuit **41A** may be

selected during the design phase of an Application Specific Integrated Circuit (ASIC). The delay time may be a function of process, voltage and temperature. For instance, if the ASIC is manufactured in a slow corner the delay may be greater, but commensurate with the type of transients generated by the logic circuits in the ASIC.

[0052] The second stage output buffer **43** may be a C-gate **43A**. In the embodiment shown, the C-gate **43A** may be comprised of two series PMOS transistors **74**, **76** and two series NMOS transistors **78**, **80**. Each input **53A** and **53B** of the C-gate **43A** controls the gate of one PMOS transistor **74** or **76** and one NMOS transistor **78** or **80**. In the embodiment shown, the input **53A** can control the gate of PMOS transistor **74** and the gate of NMOS transistor **80**. The input **53B** can control the gate of PMOS transistor **76** and the gate of NMOS transistor **78**.

[0053] The output of the pass gate **30A** may be sent to input **53A** of the C-gate **43A** and the fixed delay circuit **41A**. The output of the fixed delay circuit **41A** may be sent to the input **53B** of the C-gate **43A**. When the inputs **53A** and **53B** of the C-gate **43A** match, the C-gate **43A** may act as an inverter. When the inputs **53A** and **53B** of the C-gate **43A** do not match, the C-gate **43A** may not drive its output (high impedance state), and the output of the C-gate **43A** may maintain its current value. The output from the C-gate **43A** may then be sent to an inverter **86**.

[0054] The spacing needed to reduce double-node strikes of the C-gate **43A** to an acceptable level may be attained by interleaving the PMOS transistors **74, 76** and the NMOS transistors **78, 80** in the C-gate **43A**. The second stage delay circuit **41** may be placed between the interleaved PMOS transistors **74, 76**, and between the interleaved NMOS transistors **78, 80** in the C-gate **43A**, in order to achieve the desired node spacing without any wasted space.

[0055] The flip flop **10A** of **Figures 1** and **2** is highly tolerant to transients and upsets, utilizes the lowest energy, and puts the lowest load on the global clock tree. The setup time of the flip flop **10A** is equivalent to that of a Dual Interlock Cell (DICE) flip-flop with a fixed-delay filter in the data input, but has a larger clock input to flip-flop output (CLK-to-Q) delay.

[0056] The flip flop **10A** may be considered as a low power embodiment. The first stage interleaved filter **32** and the second stage interleaved filter **36** of the flip flop **10A** may be configured to each have a fixed delay time. The configuration of the first stage and second stage interleaved filters **32** and **36** respectively may allow the flip flop **10A** to utilize a lower amount of energy than the embodiments that will be described below. Thus, the flip flop **10A** may be considered as a low power embodiment.

[0057] Referring now to **Figures 3** and **4**, another embodiment of the flip flop **10B** is shown. The flip flop **10B** may have an input buffer **14**. In the present embodiment, the input buffer **14** may be an inverter **14A**. The inverter may be formed of a pair of transistors **16** and **18**. The pair of transistors **16** and **18** may be complementary MOSFETS. As shown, the transistor **16** may be a P-type transistor such as a P-type MOSFET, while the transistor **18** may be an N-type transistor such as an N-type MOSFET. The transistor **16** may be coupled to a voltage supply **VDD**, while the transistor **18** may be coupled to a voltage supply **VSS**.

[0058] A switching device **20** may be coupled to an output of the inverter **14A**. The switching device **20** may be used to pass on the output of the inverter **14A**. In accordance with one embodiment, the switching device **20** may be a pass gate **20A**. The pass gate **20A** may be used to pass on the logic level output from the inverter **14A** to a first stage **26** of the flip flop **10B**. The pass gate **20A** may be formed of a pair of transistors **22** and **24**. As shown, the transistor **22** may be a P-type transistor such as a P-type MOSFET, while the transistor **24** may be an N-type transistor such as an N-type MOSFET. The transistor **22** may be coupled to a clock signal **CLK**, while the transistor **24** may be coupled to an inverted clock signal **NCLK**.

[0059] In the present embodiment, the flip flop **10B** is a multi-stage flip flop having a first stage **26** and a second stage

**28.** A switching device **30** may be positioned between an output of the first stage **26** and an input of the second stage **28**. In accordance with one embodiment, the switching device **30** is a pass gate **30A** which may be used to pass the logic level output from the first stage **26** to the input of the second stage **28**. The pass gate **30A** may be formed of a pair of transistors **60** and **62**. As shown, the transistor **60** may be a P-type transistor such as a P-type MOSFET, while the transistor **62** may be an N-type transistor such as an N-type MOSFET. The transistor **62** may be coupled to the clock signal **CLK**, while the transistor **60** may be coupled to the inverted clock signal **NCLK**.

**[0060]** In the present embodiment, the first stage **26** may have a first stage interleaved filter **32**. A first stage feedback inverter **34** may be coupled between the output of the first stage interleaved filter **32** and the input of the first stage interleaved filter **32**. The second stage **28** may have a second stage selectable interleaved filter **36A**. A second stage feedback inverter **38** may be coupled between the output of the second stage selectable interleaved filter **36A** and the input of the second stage selectable interleaved filter **36A**.

**[0061]** The first stage interleaved filter **32** is configured to cut off transients coming from the logic preceding the flip-flop **10B** when the inverted clock signal **NCLK** on the pass gate **20A** is **ON**, and any transients generated within the pass gate **20A**, any

transients generated within the first stage feedback inverter **34**, and any transients generated within the first stage interleaved filter **32** when the inverted clock signal **NCLK** on the pass gate **20A** is **OFF**. Likewise, the second stage selectable interleaved filter **36A** is configured to cut off transients generated within the first stage interleaved filter **32** when the clock signal **CLK** on the pass gate **30A** is **ON**, and any transients generated within the pass gate **30A** used to pass the logic level output from the first stage **26** to the input of the second stage **28**, and any transients generated within the second stage feedback inverter **38**, and any transients generated within the second stage selectable interleaved filter **36A** of the second stage **28** when the clock signal **CLK** on the pass gate **30A** is **OFF**.

[0062] As shown in **Figure 4**, the first stage interleaved filter **32** may be formed of a first stage delay circuit **40** and a first stage output buffer **42**. In the present embodiment, the first stage delay circuit **40** may be fixed delay circuit **40A**. The fixed delay circuit **40A** may be comprised of a plurality of series connected transistor delay elements **39** which provide a delay of a fixed duration. The duration of the fixed delay circuit **40A** may be selected during the design phase of an Application Specific Integrated Circuit (ASIC). The delay time may be a function of process, voltage and temperature. For instance, if the ASIC is manufactured in a slow corner the delay

may be greater, but commensurate with the type of transients generated by the logic circuits in the ASIC.

[0063] The first stage output buffer **42** may be a C-gate **42A**. In the embodiment shown, the C-gate **42A** may be comprised of two series PMOS transistors **44**, **46** and two series NMOS transistors **48**, **50**. Each input **52A** and **52B** of the C-gate **42A** controls the gate of one PMOS transistor **44** or **46** and one NMOS transistor **48** or **50**. In the embodiment shown, the input **52A** can control the gate of PMOS transistor **44** and the gate of NMOS transistor **50**. The input **52B** can control the gate of PMOS transistor **46** and the gate of NMOS transistor **48**.

[0064] The output of the pass gate **20A** may be sent to input **52A** of the C-gate **42A** and the fixed delay circuit **40A**. The output of the fixed delay circuit **40A** may be sent to the input **52B** of the C-gate **42A**. When the inputs **52A** and **52B** of the C-gate **42A** match, the C-gate **42A** may act as an inverter. When the inputs **52A** and **52B** of the C-gate **42A** do not match, the C-gate **42A** may not drive its output (high impedance state), and the output of the C-gate **42A** may maintain its current value.

[0065] The spacing needed to reduce double-node strikes of the C-gate **42A** to an acceptable level may be attained by interleaving the PMOS transistors **44**, **46** and the NMOS transistors **48**, **50** in the C-gate **42A**. The first stage delay circuit **40** may be placed between the interleaved PMOS

transistors **44**, **46**, and between the interleaved NMOS transistors **48**, **50** in the C-gate **42A**, in order to achieve the desired node spacing without any wasted space.

[0066] In **Figures 3 and 4**, the second stage selectable interleaved filter **36A** may be formed of a second stage delay circuit **41** and a second stage output buffer **43**. In this embodiment, the second stage delay circuit **41** is a selectable delay circuit **41B**. The selectable delay circuit **41B** may be comprised of a plurality of series connected transistor delay elements **47** each of which provide a delay of a fixed duration. Each transistor delay element **47** is similar to that shown for the transistor delay elements **39** of the fixed delay circuit **40A**. The duration of each transistor delay element **47** may be selected during the design phase of an ASIC. The delay may be a function of process, voltage and temperature.

[0067] Each of the transistor delay elements **47** may be coupled to a multiplexer **51**. The transistor delay elements **47** may be placed serially back to back with the output of each transistor delay element **47** coupled to an input of the multiplexer **51** and to the input of the subsequent transistor delay element **47**. The output of the multiplexer **51** may be connected to the second input **53B** of the C-gate **43A**. One or more select signals may be sent to the multiplexer **51** and may be used to configure the selectable delay circuit **41B** to a user

selected, desired programmable time delay. The select signals may be used to send signals to the multiplexer **51** to select which outputs from the transistor delay elements **47** are sent to the second input **53B** of the C-gate **43A**. In the present embodiment, the select signals **NCLK** and **CLK** may be sent to the multiplexer **51** and used to configure the selectable delay circuit **41B**. In another embodiment, user controlled select signals tied to input pins of the ASIC may be sent to the multiplexer **51** and used to configure the selectable delay circuit **41B**.

[0068] The second stage output buffer **43** may be a C-gate **43A**. In the embodiment shown, the C-gate **43A** may be comprised of two series PMOS transistors **74**, **76** and two series NMOS transistors **78**, **80**. Each input **53A** and **53B** of the C-gate **43A** controls the gate of one PMOS transistor **74** or **76** and one NMOS transistor **78** or **80**. In the embodiment shown, the input **53A** can control the gate of PMOS transistor **74** and the gate of NMOS transistor **80**. The input **53B** can control the gate of PMOS transistor **76** and the gate of NMOS transistor **78**.

[0069] The output of the pass gate **30A** may be sent to input **53A** of the C-gate **43A** and the selectable delay circuit **41B**. The output of the selectable delay circuit **41B** may be sent to the input **53B** of the C-gate **43A**. When the inputs **53A** and **53B** of the C-gate **43A** match, the C-gate **43A** may act as an inverter. When

the inputs **53A** and **53B** of the C-gate **43A** do not match, the C-gate **43A** may not drive its output (high impedance state), and the output of the C-gate **43A** may maintain its current value. The output from the C-gate **43A** may then be sent to an inverter **86**.

[0070] The spacing needed to reduce double-node strikes of the C-gate **43A** to an acceptable level may be attained by interleaving the PMOS transistors **74**, **76** and the NMOS transistors **78**, **80** in the C-gate **43A**. The second stage delay circuit **41** may be placed between the interleaved PMOS transistors **74**, **76**, and between the interleaved NMOS transistors **78**, **80** in the C-gate **43A**, in order to achieve the desired node spacing without any wasted space.

[0071] In the flip flop **10B**, the first stage **26** has a first stage interleaved filter **32** having a fixed delay that cuts off the majority of transients generated in the logic preceding the flip-flop **10B**. The second stage **28** of the flip flop **10B** has a second stage selectable interleaved filter **36A** with multiple transistor delay elements **47** and the select input of the multiplexer **51** tied to the second stage latch clock **NCLK**. When the second stage latch clock gate is **ON**, the shortest delay is selected, resulting in a smaller CLK-to-Q delay, a critical flip-flop performance parameter. When the second stage latch clock gate is **OFF**, the larger delay is selected to provide greater

immunity to upsets. The flip-flop **10B** is highly tolerant to transients and upsets, utilizes only 6% more energy, and puts only 15% more load on the global clock tree than the low power version. Its setup time and CLK-to-Q delay are equivalent to that of a DICE flip-flop with a fixed-delay filter in the data input.

**[0072]** The flip flop **10B** may be considered as a balanced embodiment. The flip flop **10B** may be configured to have a first stage **26** and a second stage **28** wherein the first stage **26** has a first stage interleaved filter **32** and the second stage **28** has a second stage selectable interleaved filter **36A**. In the balanced embodiment, the first stage interleaved filter **32** is configured to have a fixed delay time, while the second stage selectable interleaved filter **36A** has a selectable delay time. The flip flop **10B** may be considered as a balanced embodiment as the flip flop **10B** allows one to select the delay time of the second stage selectable interleaved filter **36A**. However, the ability to select the delay time for the second stage selectable interleaved filter **36A** increases the power consumption of the flip flop **10B** as compared to the flip flop **10A**.

**[0073]** Referring now to **Figures 5-6**, another implementation of the flip flop **10C** is shown. The flip flop **10C** may have an input buffer **14**. In the present embodiment, the input buffer **14** may be an inverter **14A**. The inverter **14A** may be formed of a pair of transistors **16** and **18**. The pair of transistors **16** and

**18** may be complementary MOSFETS. As shown, the transistor **16** may be a P-type transistor such as a P-type MOSFET, while the transistor **18** may be an N-type transistor such as an N-type MOSFET. The transistor **16** may be coupled to a voltage supply **VDD**, while the transistor **18** may be coupled to a voltage supply **VSS**.

[0074] A switching device **20** may be coupled to an output of the inverter **14A**. The switching device **20** may be used to pass on the output of the inverter **14A**. In accordance with one embodiment, the switching device **20** may be a pass gate **20A**. The pass gate **20A** may be used to pass on the logic level output from the inverter **14A** to a first stage **26** of the flip flop **10C**. The pass gate **20A** may be formed of a pair of transistors **22** and **24**. As shown, the transistor **22** may be a P-type transistor such as a P-type MOSFET, while the transistor **24** may be an N-type transistor such as an N-type MOSFET. The transistor **22** may be coupled to a clock signal **CLK**, while the transistor **24** may be coupled to an inverted clock signal **NCLK**.

[0075] In the present embodiment, the flip flop **10C** is a multi-stage flip flop having a first stage **26** and a second stage **28**. A switching device **30** may be positioned between an output of the first stage **26** and an input of the second stage **28**. In accordance with one embodiment, the switching device **30** is a pass gate **30A** which may be used to pass the logic level output

from the first stage **26** to the input of the second stage **28**. The pass gate **30A** may be formed of a pair of transistors **60** and **62**. As shown, the transistor **60** may be a P-type transistor such as a P-type MOSFET, while the transistor **62** may be an N-type transistor such as an N-type MOSFET. The transistor **62** may be coupled to the clock signal **CLK**, while the transistor **60** may be coupled to the inverted clock signal **NCLK**.

**[0076]** In the present embodiment, the first stage **26** may have a first stage selectable interleaved filter **32A**. A first stage feedback inverter **34** may be coupled between the output of the first stage selectable interleaved filter **32A** and the input of the first stage selectable interleaved filter **32A**. The second stage **28** may have a second stage selectable interleaved filter **36A**. A second stage feedback inverter **38** may be coupled between the output of the second stage selectable interleaved filter **36A** and the input of the second stage selectable interleaved filter **36A**.

**[0077]** The first selectable interleaved filter **32A** is configured to cut off transients coming from the logic preceding the flip-flop **10C** when the inverted clock signal **NCLK** on the pass gate **20A** is **ON**, and any transients generated within the pass gate **20A**, any transients generated within the first stage feedback inverter **34**, and any transients generated within the first stage selectable interleaved filter **32A** when the inverted clock signal

**NCLK** on the pass gate **20A** is **OFF**. Likewise, the second stage selectable interleaved filter **36A** is configured to cut off transients generated within the first stage interleaved filter **32A** when the clock signal **CLK** on the pass gate **30A** is **ON**, and any transients generated within the pass gate **30A** used to pass the logic level output from the first stage **26** to the input of the second stage **28**, and any transients generated within the second stage feedback inverter **38**, and any transients generated within the second stage selectable interleaved filter **36A** when the clock signal **CLK** on the pass gate **30A** is **OFF**.

[0078] As shown in **Figure 6**, the first stage selectable interleaved filter **32A** may be formed of a selectable delay circuit **40B** and a first stage output buffer **42**. In the present embodiment, the selectable delay circuit **40B** may be comprised of a plurality of series connected transistor delay elements **39**. The duration of each transistor delay element **39** may be selected during the design phase of an ASIC. The delay may be a function of process, voltage and temperature.

[0079] Each of the transistor delay elements **39** may be coupled to a multiplexer **31**. The transistor delay elements **39** may be placed serially back to back with the output of each transistor delay element **39** coupled to an input of the multiplexer **31** and to the input of the subsequent transistor delay element **39**. The output of the multiplexer **31** may be

connected to the second input **52B** of the C-gate **42A**. One or more select signals **CLK** may be sent to the multiplexer **31** and may be used to configure the selectable delay circuit **40B** to a user selected, desired programmable time delay. The select signals **CLK** may be used to send signals to the multiplexer **31** to select which outputs from the transistor delay elements **39** are sent to the second input **52B** of the C-gate **42A**.

**[0080]** The first stage output buffer **42** may be a C-gate **42A**. In the embodiment shown, the C-gate **42A** may be comprised of two series PMOS transistors **44**, **46** and two series NMOS transistors **48**, **50**. Each input **52A** and **52B** of the C-gate **42A** controls the gate of one PMOS transistor **44** or **46** and one NMOS transistor **48** or **50**. In the embodiment shown, the input **52A** can control the gate of PMOS transistor **44** and the gate of NMOS transistor **50**. The input **52B** can control the gate of PMOS transistor **46** and the gate of NMOS transistor **48**.

**[0081]** The output of the pass gate **20A** may be sent to input **52A** of the C-gate **42A** and the selectable delay circuit **40B**. The output of the selectable delay circuit **40B** may be sent to the input **52B** of the C-gate **42A**. When the inputs **52A** and **52B** of the C-gate **42A** match, the C-gate **42A** may act as an inverter. When the inputs **52A** and **52B** of the C-gate **42A** do not match, the C-gate **42A** may not drive its output (high impedance state), and the output of the C-gate **42A** may maintain its current value.

[0082] The spacing needed to reduce double-node strikes of the C-gate **42A** to an acceptable level may be attained by interleaving the PMOS transistors **44, 46** and the NMOS transistors **48, 50** in the C-gate **42A**. The selectable delay circuit **40B** may be placed between the interleaved PMOS transistors **44, 46**, and between the interleaved NMOS transistors **48, 50** in the C-gate **42A**, in order to achieve the desired node spacing without any wasted space.

[0083] In **Figures 5 and 6**, the second stage selectable interleaved filter **36A** may be formed of a second stage delay circuit **41** and a second stage output buffer **43**. In this embodiment, the second stage delay circuit **41** is a second stage selectable delay circuit **41B**. The second stage selectable delay circuit **41B** may be comprised of a plurality of transistor delay elements **47**. Each transistor delay element **47** may be comprised of series connected transistors similar to that shown for the fixed delay circuit **41A**. The duration of each transistor delay element **47** may be selected during the design phase of an ASIC. The delay may be a function of process, voltage and temperature.

[0084] Each of the transistor delay elements **47** may be coupled to a multiplexer **51**. The transistor delay elements **47** may be placed serially back to back with the output of each transistor delay element **47** coupled to an input of the multiplexer **51** and to the input of the subsequent transistor

delay element **47**. The output of the multiplexer **51** may be connected to the second input **53B** of the C-gate **43A**. One or more select signals **NCLK** may be sent to the multiplexer **51** and may be used to configure the selectable delay circuit **41B** to a user selected, desired programmable time delay. The select signals **NCLK** may be used to send signals to the multiplexer **51** to select which outputs from the fixed delay circuits **47** are sent to the second input **53B** of the C-gate **43A**.

[0085] The second stage output buffer **43** may be a C-gate **43A**. In the embodiment shown, the C-gate **43A** may be comprised of two series PMOS transistors **74**, **76** and two series NMOS transistors **78**, **80**. Each input **53A** and **53B** of the C-gate **43A** controls the gate of one PMOS transistor **74** or **76** and one NMOS transistor **78** or **80**. In the embodiment shown, the input **53A** can control the gate of PMOS transistor **74** and the gate of NMOS transistor **80**. The input **53B** can control the gate of PMOS transistor **76** and the gate of NMOS transistor **78**.

[0086] The output of the pass gate **30A** may be sent to input **53A** of the C-gate **43A** and the selectable delay circuit **41B**. The output of the selectable delay circuit **41B** may be sent to the input **53B** of the C-gate **43A**. When the inputs **53A** and **53B** of the C-gate **43A** match, the C-gate **43A** may act as an inverter. When the inputs **53A** and **53B** of the C-gate **43A** do not match, the C-gate **43A** may not drive its output (high impedance state), and

the output of the C-gate **43A** may maintain its current value. The output from the C-gate **43A** may then be sent to an inverter **86**.

**[0087]** The spacing needed to reduce double-node strikes of the C-gate **43A** to an acceptable level may be attained by interleaving the PMOS transistors **74, 76** and the NMOS transistors **78, 80** in the C-gate **43A**. The selectable delay circuit **41B** may be placed between the interleaved PMOS transistors **74, 76**, and between the interleaved NMOS transistors **78, 80** in the C-gate **43A**, in order to achieve the desired node spacing without any wasted space.

**[0088]** The flip flop **10C** has a reduced setup time using a first stage selectable interleaved filter **32A** with multiple delays and the multiplexer select input tied to the master latch clock for the first stage **26**. When the master latch clock gate is **ON**, i.e., when the inverted clock signal **NCLK** is **ON**, the smaller delay is selected, reducing the flip-flop setup time, trading off single event transient immunity for increased electrical performance. When the master latch clock gate is **OFF**, i.e., when the inverted clock signal **NCLK** is **OFF**, the larger delay is selected, preserving the flip-flop's robust SEU characteristics. The second stage **28** has the same design as in **Figure 3-4**. This implementation would be useful in critical timing paths where a faster flip-flop is needed. The flip flop

**10C** is highly tolerant to upsets, but less tolerant to transients, utilizes 15% more energy, and puts 30% more load on the global clock tree than the low power version. Its setup time and CLK-to-Q delay are equivalent to that of a DICE flip-flop without a filter.

[0089] The flip flop **10B** may be considered as a high performance embodiment. The flip flop **10C** may be configured to have a first stage **26** having a first stage selectable interleaved filter **32A** and a second stage **28** having a second stage selectable interleaved filter **36A**. In the high performance embodiment, the first stage and second stage selectable interleaved filters **32A** and **36A** respectively are configured to have a selectable delay time. Thus, the delay time for both the first stage and second stage selectable interleaved filters **32A** and **36A** respectively may be selected based on a desired time delay. The flip flop **10C** is a high performance embodiment that would be useful in critical timing paths where a faster flip-flop may be needed.

[0090] While embodiments of the disclosure have been described in terms of various specific embodiments, those skilled in the art will recognize that the embodiments of the disclosure may be practiced with modifications within the spirit and scope of the claims.

What is claimed is:

1. A flip flop circuit, comprising:
  - a first stage; and
  - a second stage,wherein the first stage and the second stage each have interleaved filters, wherein the interleaved filter of the first stage comprises:
  - a first stage delay circuit; and
  - a first stage output buffer having a first input coupled to an input of the flip flop circuit and a second input coupled to an output of the first stage delay circuit, wherein the first stage delay circuit has a selectable delay programmable through an input clock signal.
2. The flip flop circuit in accordance with claim 1, further comprising a first stage feedback inverter coupled between an output of the first stage output buffer and the input of the flip flop.
3. The flip flop circuit in accordance with claim 1, wherein the first stage delay circuit has a fixed delay.
4. The flip flop circuit in accordance with claim 1, wherein the interleaved filter of the second stage comprises:
  - a second stage delay circuit; and
  - a second stage output buffer having a first input coupled to an input of the second stage and a second input coupled to an output of the second stage delay circuit.

5. The flip flop circuit in accordance with claim 4, further comprising a second stage feedback inverter coupled between an output of the second stage output buffer and the input of the second stage.
6. The flip flop circuit in accordance with claim 4, wherein the second stage delay circuit has a fixed delay.
7. The flip flop circuit in accordance with claim 4, wherein the second stage delay circuit has a selectable delay programmable through an input clock signal.
8. A flip flop circuit comprising:
- a first stage comprising:
    - a first stage interleaved filter having a first stage interleaved filter input and a first stage interleaved filter output; and
    - a first stage feedback inverter coupled to the first stage interleaved filter input and to the first stage interleaved filter output;
  - a second stage comprising:
    - a second stage interleaved filter having a second stage interleaved filter input and a second stage interleaved filter output;
  - and
  - a second stage feedback inverter coupled to the second stage interleaved filter input and to the second stage interleaved filter output; and
  - a switching device coupled between the first stage and the second stage;
- wherein the first stage interleaved filter comprises:
- a first stage delay circuit, wherein the first stage delay circuit is a selectable delay programmable through an input clock signal; and

a first stage output buffer coupled to the first stage delay circuit, wherein the first stage output buffer comprises a plurality of transistors, wherein the plurality of transistors are interleaved.

9. The flip flop circuit in accordance with claim 8, wherein the second stage interleaved filter comprises:

a second stage delay circuit; and

a second stage output buffer coupled to the second stage delay circuit, wherein the second stage output buffer comprises a plurality of transistors, wherein the plurality of transistors are interleaved.

10. The flip flop circuit in accordance with claim 10, wherein the second stage delay circuit has a fixed delay.

11. The flip flop circuit in accordance with claim 10, wherein the second stage delay circuit has a selectable delay programmable through an input clock signal.

12. A multi-stage flip flop circuit comprising:

a first stage interleaved filter coupled to an input of the multi-stage flip flop;

a first stage feedback inverter coupled to the input of the multi-stage flip flop and to a first stage interleaved filter output;

a second stage interleaved filter coupled to the first stage interleaved filter output;

a second stage feedback inverter coupled to the first stage interleaved filter output and to a second stage interleaved filter output; and

a switching device coupled between the first stage and the second stage;

wherein the first stage interleaved filter has a delay circuit and the second stage interleaved filter has a selectable delay circuit having a selectable delay programmable through an input clock signal.

13. The multi-stage flip flop circuit in accordance with claim 12, wherein the first stage interleaved filter delay circuit is a selectable delay circuit having a selectable delay programmable through an input clock signal.

14. The multi-stage flip flop circuit in accordance with claim 12, wherein the first stage interleaved filter delay circuit is a fixed delay circuit.