Highly non-linear encoders for Current Mode Multiple-Valued Logic

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Abstract:

This paper describes the use of highly non-linear encoders to provide low power Current Mode Multiple Valued Logic (CMMVL) circuits. A maximum function is shown, that consumes much less power than previously reported circuits. The encoding system is based upon using a single transistor between the encoder output and ground to provide a 'very negative' signal that overrides any other connection to the output node.

Introduction

Current Mode Multiple Valued Logic (CMMVL) uses the size (and sometimes sign) of a current to represent the value of a signal. Kirchhoffs current law allows two currents to be summed on a node, and previously reported applications use this to form adders [1,2]. It is possible to form other functions such as single digit products [3]. In this paper the use of highly non-linear current mode encoders is discussed. One possible output of an encoder is described simply as 'very negative', and can be used as an overriding signal. The highly non-linear encodings lead to circuits capable of forming any logical function, and require very low resolution from the fabrication process.

Circuits designed using current mode MVL will only be efficient in terms of time, area and power if they take full advantage of the summing node. Because of this, any methodology for current mode MVL design must focus on this. Circuits can have many inputs, that enter the cell by the same physical connection, and these can be formed in a manner of the designer's choice so that the decoding logic is simple. Current mode circuits can generally be decomposed into the free summing function and three distinct sections: a decoder, binary logic (which is not always present), and an encoder circuit. This form is shown in figure 1. The inputs to the circuit are summed on the input node and fed to the decoder. The decoder produces a set of binary signals each of which indicates whether the input current total was above or below a particular current level. These signals can then be adapted by the binary circuits to form signals that can correctly operate the encoders which provide the current mode output signal. This structure has been shown in Current's Quaternary Full Adder (QFA) [1].

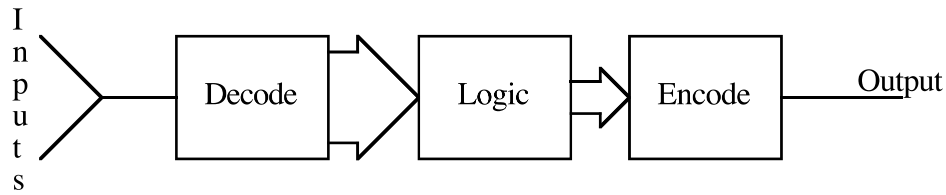


Figure 1. Decomposition of a current mode circuit.

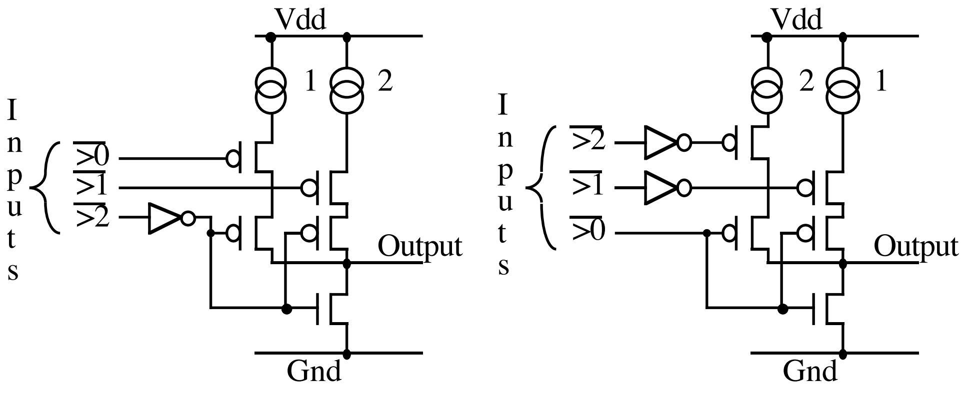
If a circuit has two input values x and y, and they have been encoded as currents using the functions A(), and B() respectively, then when they are summed together, the sum is equal to A(x)+B(y). The functions A() and B() may be linear, and may be the same as each other. The summed current is then decoded and acted on by the logic, which can be represented by the function C(). Hence the value that the final encoder encodes is C(A(x)+B(y)). For a full adder, there are two outputs, and each has its own function C(). The carry function is in effect a quantised division by four, and the sum output is a modulo four function.

The "grounded output" encoding

In certain situations, an encoder can be designed so that a negative current does not have any specified current itself, but instead can sink so much current that the node is grounded when that encoding is specified. This can be demonstrated by the use of an example: the maximum circuit. An encoding is shown in table 1, with the output of <<0 for an input value of 3. This means that if the first encoder has a 3 as its input, the output of the second encoder will flow into the first encoder rather than the decoder. The decoder input stage is uni-directional, so the current flowing into the first encoder is the current output by the second encoder. The decoder will detect no current since it all flows into the first encoder. A 1 unit current source is added to the node unswitched to allow the circuit to differentiate between and input of 0 on both inputs and an input of 3 on either. This form of encoding is very simple to produce, as shown in figure 2a. The n-type transistor must be made large enough that it can sink the maximum output current from the other encoder, and the 1 unit unswitched current source, with a negligible voltage drop across it. The n-type transistor does not have to sink current from its own current sources since it is switched so that only the current source or sink is on at any one time, and not both.

input	A(input)	B(input)
0	0	0
1	1	1
2	3	3
3	<<0	<<0

Table 1. A maximum function encoding that uses a grounding output.



a) b)

Figure 2. The encoder for the maximum function. a) normal, b) complemented

The sum of input currents verses the output value required for those inputs is given in table 2. The maximum current for this encoding is considerably lower than is possible using more conventional encodings. The thresholds for this encoding are 0.5, 1.5, and 3.5 current units. The decoder required for the grounding output encoding of the maximum function is shown in figure 3.

	Max			
Current	0	1	2	3
0				✓
1	✓			
2		✓		
3		✓		
4			✓	
5			✓	
7			✓	

Table 2. The sum of currents vs. output value for the grounding output encoding (including 1 current unit unswitched source).

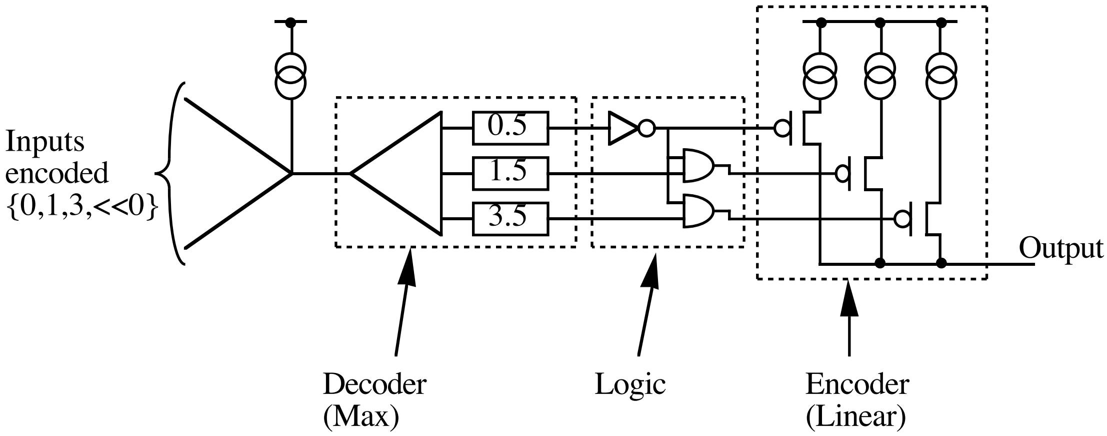


Figure 3. The maximum function decoder and logic for use with the grounding output encoders.

The grounding output encoder can only be used with a specific type of function, because if one encoder grounds the node, there is no way of distinguishing between the different outputs of the other encoder. Hence the grounding output can only be used if one particular input value to one of the encoders always results in the same output regardless of the other encoders input value. In the case of the maximum function, if either encoder has a 3 input to it, then the output must be a 3, and so the input value 3 can be used to ground the summing node.

The grounding output is clearly very useful, but there is one disadvantage to this kind of encoding. It is not possible to bias the input node which would be an advantage since the current mode mirrors can be made faster if they are biased with a small amount of current so that they are always conducting.

A current mode MVL logic set

A full set of logical functions can be created from a maximum function so long as the output can be complemented. The minimum function is used with the maximum function, but this can be created by inverting the inputs and output of a maximum function. The grounded output encoding can be complemented as shown in figure 2b. The inverters may be omitted if n-type transistors can be used as the current switches. In this case, the complemented encoding would be smaller than the un-complemented encoding. This is because the grounding transistor must be an n-type transistor and hence the inverter in the un-complemented encoding shown in figure 2a cannot be removed. Even using p-type switch transistors, the complemented encoder uses only one more inverter (i.e. two transistors) than the un-complemented encoder.

The MAX function using optionally complemented grounded output encoders provides the ability to produce any logical function, with very low resolution requirements (maximum threshold of 3.5 current units).

Conclusions

The 'grounded output' concept of non-linear current encoding has been developed in this paper. The concept has been shown to be of use in the creation of maximum function blocks that can, with complemented outputs be used to produce any logical function. Hence, there is now the potential for a more efficient implementation of functions than those previously reported [3].

References

[1] "A CMOS multiple valued logic test chip", K.W. Current, F. Edwards and D. Freitas, Proceedings IEEE 17th International Symposium on Multiple Valued Logic, May 1987, pp. 16-19.

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[3] "VLSI Arithmetic With Current Mode Multiple Valued Logic", S. Summerfield, C.T. Clarke and G.R. Nudd, Proceedings IEEE International Symposium on Circuits and Systems 92, May 1992, pp. 3001-3004.