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Critically Analyzing the Behavior of Fuzzy Flip Flops and Searching for Better Solutions

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Abstract— Sequential circuits are the important components of a computer system as they process binary data and buffers binary output for the next period.. Sequential circuits are the interconnection of logic gates and Flip Flops and the buffering of binary output for the next period is carried out by the Flip Flops by their inherent feedback mechanism. Sequential circuits basically process binary data sequentially with an automated method of state transition which is solely driven by the Flip Flops. Among the different Flip Flops J-K Flip-Flop is the major one and the most elementary and general unit of the sequential digital circuits. In this paper the J-K Flip Flops driven by Fuzzy rules are viewed as an improvised form of the Flip Flops based on the Boolean rules and the various operative aspects of them are examined . Firstly the detailed comparison between Fuzzy logic and Boolean axiomatic properties are carried out ,then the Fuzzy logic driven Flip Flops with non associative properties are studied and the input-output relationships as well as the expressions of outputs in the next period are derived considering different combinations of the outputs in current period and inputs in the next period . At last the rules of output and different input conditions are analyzed and derived. The later part of the paper deals with the unstable situation of Fuzzy J-K Flip Flops over the different states and provides with some measure to avoid the same. Thus this paper deals with the formulation of fuzzy operational rules for the J-K Flip Flop on the one hand and attempts to find a concrete solution to the problem of unstable states of J-K fuzzy Flip Flops on the other.

Index Terms— Fuzzy J-K Flip Flop, Sequential Circuit, Triangular Norm, Triangular Co-norm, SET type Flip Flop, RESET type Flip Flop, Unstable Situation , Boolean.

1 INTRODUCTION

In this paper the elementary results of analyzing Fuzzy sequential circuit with J-K Flip-Flop is presented. Firstly the classic Fuzzy operations and the non-associative operations are examined , secondly the Boolean axiomatic properties of the J-K Flip Flops are examined in comparison with Fuzzy and later the Fuzzy J-K Flip Flops with non-associative properties are examined. It has been studied that the triangular norm(t-norm) and triangular co-norm(t-co norm) or s-norm yield different expressions for SET and RESET type respectively are proved to be equivalent and thus yield a common single expression for both the norms. As the finding of the author, the rules are derived for the output at t+1 th period at different combinations of inputs and different SET-RESET conditions of the current period. In another study it has been found that the unstable situations arise with toggled outputs in the successive states of Fuzzy J-K Flip Flop. This problem is revealed by one of the reviewed papers which has been attempted to be resolved here by a circuit mix that aims to bring steady output levels across the states with a given fixed inputs .

2 ANALYSIS STAGE

2.1 Literature Review

(1) In the paper "Non-Associative Fuzzy Flip-Flop with Dual SET-RESET Feature" by Rita Lovassy; Institute of Microelectronics and Technology, Budapest Tech, Hungary. and Laszlo T. Koczy; Institute of Information Technology, Mechanical and Electrical Engineering, Szechenyi Istvan University, Gyor, Hungary; Department of Telecommunication and Media Informatics, Budapest University of Technology and Economics, Hungary presented in the SISY 2006 - 4th Serbian-Hungarian Joint Symposium on Intelligent Systems, at first the classic Fuzzy operations and then the non associative operations are analyzed with some relevant example related to probability . In the later part the comparison between Fuzzy and Boolean flip-flops are carried out and finally the Fuzzy properties of non associative Fuzzy Flip Flops are analyzed and some important results are found. In the reviewed paper, the analysis starts with the minimal disjunctive(Sum of product) form as: $Q(t+1) = J \cdot Q(t)^c + K^c \cdot Q(t)$. Likewise the equivalent max term expression or minimized conjunctive form (product of sum) as: $Q(t+1)=(J+Q)(K^c + Q(t)^c)$

In the paper it is stated that per Boolean algebra these two are equivalent but in Fuzzy logic there is no such operation triplet for which these two are equivalent. There is no such mechanism also to prefer any one of them over the other. Thus in the reviewed paper, the concept of Hirota and Ozawa to use these two dual definitions of Fuzzy J-K Flip Flop is used. The first equation of Q(t+1) is referred by them as the output equation of the "RESET" type Fuzzy Flip Flop and the later is referred as the output equation of the "SET" type Fuzzy Flip Flop. It is clear that the maxterm of the first equation is the dual of the first equation and physically can be achieved by complementing J and K inputs with inverters.

In the reviewed paper, the attempt is made to find out a single symmetric solution combining SET and RESET type equations with non associative properties.The non associative Fuzzy Flip Flop is discussed with a reference to Fodor and Koczy. The formulation is as follows:

P1 : F(0,0,Q) = Q,

P2 : F(0,1,Q) = 0,

P3: F(1,0,Q) = 1,

P4: F(1,1,Q)=n(Q) where n is the strong negation of Q which is consistent to the Boolean concept of toggling of t th period's output in t+1 th period where both J and K are 1.

P5: F(e, e,Q)=e where e =n(e) is any equilibrium and n is the strong negation.

Combining P2, P3 and P5 we get,

P(6)= F(D,n(D),Q) =D where D €[0,1].

These all formulations are consistent with the Boolean logic identities. Now according to the Lucasiewicz norms the output of the RESET type flip-flop :

Q_R (t+1) = min [T(J,1-Q) + T(1-K,Q),1].

Or we can write,

Q_R (t+1) = T(J,1-Q) + T(1-K,Q) -------------------------------1.

Similarly for SET type Flip Flop,

Q_S (t+1) = max[S(J,Q)+S((1-K),(1-Q))-1,0]

Or we can write,

Q_S (t+1) = S(J,Q)+S((1-K),(1-Q))-1------------------------------2.

We can clearly see that the output equation of RESET type Flip Flop is represented by Fuzzy T-norm and SET type by Fuzzy S-norm or T-co norm.. Now from 1 and 2,

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Q_R(t+1)={min(J,1-Q)+max(J-Q,0)/2+{min(1-K,Q)

+max(Q-K,0)}/2 --------3.

This is achieved by using the mid-point based numerical estimation based on

p= [{max(P_1+P_2-1),0},{min(P_1,P_2)}]. As T(J,1-Q) and T(1-K,Q) are Fuzzy T-norms or or intersection, that's why this formulation is used. Similarly, using the concept of UNION of subjective probabilities p=[{max(P_1,P_2)},{min(P_1+P_2),1}] and by using the midpoint based numerical estimation,

Q_S (t+1)= [{max(J, Q)+min(J+Q,1)}/2 + {max(1-K,1-Q)+min((1-K+1-Q),0)}/2] -1

Or

Q_S (t+1)= [{max(J, Q)+ max(1-K,1-Q)}-1]/2 +

[{ min(J+Q,1)+min((2-K-Q),1)}-1]/2 -----------4

Now in the reviewed paper it has been proved that Q_R (t+1) =Q_S (t+1) and they give a single expression for the output of Fuzzy flip-flop. Finally it has been implicitly proved that the SET and RESET equations are equivalent in Fuzzy flip-flop and thus there is no distinction between SET type and RESET type. A single expression of Fuzzy flip-flop output for different combinations of J,K and Q(t) is achieved.

It has been proved that

min(J,1-Q)+max(J-Q,0) + min(1-K,Q)+max(Q-K,0)

= max(J, Q)+ max(1-K,1-Q)}

+ min(J+Q,1)+min((2-K-Q),1)}-2

Now there are 3! . 2^3 =48 combinations of J, K, Q(t),J^c K^c $Q(t)^c$ These 48 cases are not all essentially different. Any variable and its negated are symmetrical to the equilibrium *e*=0.5.Consequently, for describing a case it is sufficient to tell which one of the ponated or negated version of each of the three variables is less, greater or equal than *e*. The 8 main cases to be considered are as follows: J^c K^c $Q(t)^c$, J^c K^c Q(t) , J^c K $Q(t)^c$, J^c KQ(t) , J K^c $Q(t)^c$ J K^c Q(t) , J K $Q(t)^c$, J K Q(t) . For each combination there are 3! =6 sub cases depending on the sequence of these three. Thus these are total 48 sub cases where some sub cases are giving identical results for Q_R and

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Q_S . It has been observed that these are only 13 out of 48 sub cases are essentially different and those are listed in the table :

The first column of the table contains the serial number of the essentially different sub-case; the second column describes the inequality conditions applying for the given essential sub-case, while the third column gives the identical value of $2Q_R$ and $2Q_S$ in the given sub-case.Now it is clear that for all these essentially different sub cases, Q_S and Q_R gives single expression(as shown in the third column) and so it has been concluded that Q_S and Q_R are identical. Now some concrete rule base and conditional formulation should be there to explain these cases in a well formatted way.

(2) In the paper " New Components for building Fuzzy logic circuits" the authors Ben Choi and Kunal Tipnis of Lousiana Technological University has pointed out the case of several unstable conditions arise for the SET type and RESET type J-K Fuzzy Flip Flops. Some examples are provided as:

Initial Q	J	K	Q(t)	Q(t+1)	Q(t+2)
0	4	4	4	2	4
2	4	4	4	2	4
4	4	4	2	4	2
6	4	4	2	4	2

(1)

Here 6 Volt represents logic 1 and 0 volt represent logic 0 and 2 Volt and 4 Volt represents logic level .334 and .667 respectively.

While the initial stored value of Q is 0 volt and when given 4 volts of inputs for J and K , the resulting q will be continuously toggling between 2V and 4V. Similar types of unstable condition will appears when the initial stored value is 2 Volts and given 4 Volts of inputs for J and K. Other unstable conditions are also stated to take place when J=K=6 , J=4 k=6 and J=6 K=4.

(2)

It has been pointed out that neither the SET type nor the RESET type can solve the problem of unstable state. In this paper they used Hirota's technique of combining the SET type and RESET type equation is used.:

$$Q(t+1) = \{ J \vee (1-K)\} \wedge \{ J \vee Q(t)\} \wedge \{ (1-K) \vee (1-Q(t)\}$$

This combined equation minimizes the unstable states but can't completely solve it as there are still some unstable states observed. As a suggestive measure the new Fuzzy D type Flip Flop has been referred as in D type Fuzzy Flip Flop J and K inputs can be complements to each other only. Other

Case	Conditions	$2\ Q_R(t+1) = 2\ Q_S(t+1)$
1	J,K <=Q,¬Q	J- K +2Q
2	J, ¬K<=Q,¬Q K, ¬J <= Q,¬Q	1+J-K
3	¬J, ¬K <= Q,¬Q	2+J-K-2Q
4	J, Q <= K,¬K	J+Q
5	J, ¬Q <= K,¬K	1+J-2K +Q
6	¬J, Q <= K,¬K	1+J-Q
7	¬J, C <= K,¬K	2+J-K-Q
8	K,Q <= J,¬J	2J-K+Q
9	K, ¬Q <= J,¬J	1-K+Q
10	¬K, Q <= J,¬J	1+2J-K-Q
11	¬K, ¬Q <= J,¬J	2-K-Q
12	Q<= J,K, ¬J, ¬K	2J
13	¬Q<= J,K, ¬J, ¬K	2-2K

combinations are ignored. This will eliminate the number of unstable states to some extent.

2.2 Finding of the Author

The paper by Lovassy and Koczy follows the process mentioned in the paper by Horota and ozawa in their works on the related topics. Basically it is shown that SET Type and RESET Type Flip Flop equations are equivalent and giving 13 distinguished subcases with combinations of two current period's inputs and one previous period's output. In the first reviewed paper the triangular norm and co-norm forms of Fuzzy Flip Flop operations are proved to be equivalent. However a SET of rules are further required to define the input output relations and the formulation of the outputs. Here a SET of rules and formulations are derived those are consistent for both "SET type" and "RESET type" Fuzzy Flip Flops. In the send paper reviewed points out the unstable situations and the new D type Fuzzy Flip Flop is referred as suggestive measure. However considering the power and scope of J-K Flip Flop in designing Fuzzy sequential circuit, it should be used as a prime component and D Fuzzy Flip Flop can hardly substitute it in every respect . The formulations are made to make the input-output relationship completely conditional and can clarify the unstable states as well. The formulations are as follows:

Case 1 :If J=K

Subcase-i: J=0,K=0

Q(t+1)=Q(t) – No Change , regardless of Q(t).

Subcase-ii: J<.5 and K<.5

If Q(t)<J then

Q(t+1)=J

Otherwise

If Q(t)>=J and Q(t)<= ⌐J then

Q(t+1)=Q(t) –(No Change)

Otherwise

Q(t+1)= ⌐J.

Subcase-iii. J=.5, K=.5

Q(t+1)=.5 regardless of Q(t).

Subcase-iv. J>.5, K>.5

If Q(t) < ⌐J then

Q(t+1)= J

Otherwise

If Q(t)>J then

Q(t+1)= ⌐J

Otherwise

Q(t+1)= ⌐Q(t) (Toggle)

Subcase-v. J=1,K=1

Q(t+1)= ⌐Q(t) (Toggle).

Case -2: J ≠ K and J=⌐K

Subcase i: J>K

If Q(t) (- (0,1) then

Q(t+1) = J

Otherwise

If Q(t)>=.5 then

Q(t+1) = Q(t) (No change)

Otherwise

Q(t+1)= ⌐Q(t) (Toggle)

Subcase ii: J < K

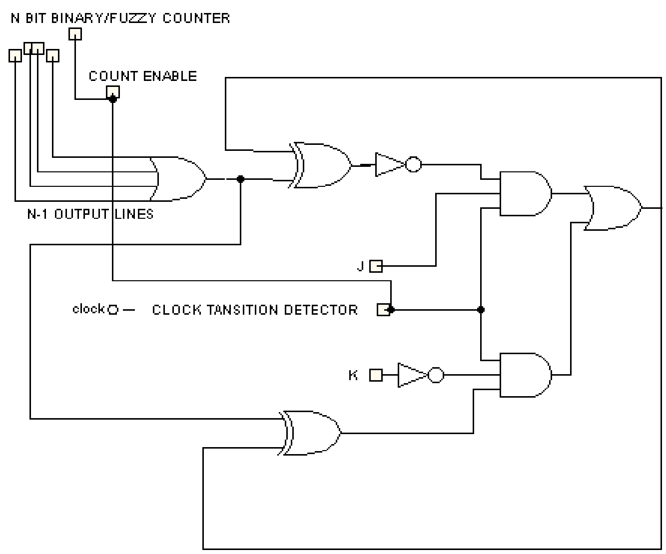
Q(t+1) =J.

This will view the system from logical point of view and the dynamic changes of output across the states are also clarified. The unstable states are all conditional and thus can be avoided instead of cutting down it's scope(by switching to D Fuzzy Flip Flop).

These results are achieved both for Q_R = (J^⌐Q) v (⌐K ^ Q). And Q_S = (J v Q)^(⌐K v ⌐Q) and by using Fuzzy MAX-MIN logic. Thus these rules are consistent for SET and RESET type Fuzzy Flip Flops.Now only two cases are considered: where J=K and where J=⌐K . These formulations are derived empirically as well as by following the output rules of Flip Flops supported by Fuzzy SET theory. Here cases and subcases define accurately all the conditions represented by the combinations of inputs and output revealed in the paper by Lovassy and Koczy.

2) In the paper by Ben Choi and Kunal Tipnis it has been pointed out the existence of unstable conditions in both SET type and RESET type flipflops. It has been examined that the technique applied by Hirota can reduce the no of unstable states but can't solve the problem. The suggested solution as derived in the research work is to feed the complemented Fuzzy input to J and K input lines from the 2nd state onwards whereas in the initial state the unmodified value of the original output should be taken. This can be done by using a counter. The count enable line of the said counter should be connected with the clock transition detector directly and the J-K Flip Flops of the counter will be provided with 0 or 1 signal (or 0V and 6V) only.Here the clock transition detector and counter follows Boolean logic but doesn't contradict with Fuzzy in the sense that they can be seen as working with terminal Fuzzy values(0 and 1 or 0V and 6V). Now as the first clock transition that will yield the output in t(1) period should suppy unmodified inputs but from the second transition onwards the complemented outputs are to be supplied as inputs. A Fuzzy OR gate should be connected to all the output lines of the J-K Flip Flops of the counter except the first one(that represents right most bit) . The output line of the Fuzzy OR gate is to be fed to the input lines of two Fuzzy XOR gates whose other

inputs are taken from the output(Q(t)) of the previous period. This system will complement the output of the previous state except in case of initial state. By doing so the unstable conditions can be avoided and the Flip Flop will produce the same output volt over the different states. This is empirically proved for the combinations in the table of the concerned reviewed paper.The suggested circuit is as follows:



Here the n-1 output lines(except the first that represent rightmost bit) are inputted to a Fuzzy OR(equivalent to Boolean OR) gate and the output will be 1(6V) for all combinations except the initial. The output from OR gate will be fed to the Fuzzy XOR gates whose other inputs are taken from the outputs of the previous state(Q(t)). As a result the XOR output will produce complement of Q s where ever the OR outputs are 1(according to the basic Boolean logic that is consistent with the Fuzzy). Thus except the initial state, for all states J and K inputs are fed by the complements of Q(t) and this will bring the stability and consistency of output for all successive states. The circuit drawn is applied for RESET TYPE Flip Flop but this same method can be applied for the SET TYPE as well. This can be somewhat mixed circuit where Clock transition detector and it's connected counter will behave according to Boolean algebra but without any contradiction with the FUZZY rules. A major aberration in this proposed Fuzzy Flip Flop except in case of initial state is : The output will be toggled in the next state for J=0 and K=0 and will remain unchanged for J=1 and K=1 and other Fuzzy combinations will behave exactly as formulated in the previous part of this paper. The mathematical formulation for the proposed RESET type Fuzzy Flip Flop is:

For t=0

Q(t+1)=max{min(j,(1-Q(t)),min((1-k),Q(t))}

For t>0

Q(t+1)= max{min{J,Q(t)),min((1-k),(1-Q(t)))}

And for the proposed RESET type Fuzzy Flip Flop is:

For t=0

Q(t +1) =min{ max(J,Q(t)),max((1-K),(1-Q(t)))}

For t>0

Q(t +1) =min{ max((1-J),(1-Q(t))),max(K,Q(t))}

This problem may be resolved by simply connecting a Fuzzy inverter with the line that feeds back to the input gates for the next period. By doing this, the table becomes:

Initial Q	J	K	Q(t)	Q(t+1)	Q(t+2)
0	4	4	2	2	2
2	4	4	2	2	2
4	4	4	4	4	4
6	4	4	4	4	4

This solution yields some interesting results:

i) When J and K are set to 4V(.67 Fuzzy Value) each then upto 2V(.33 Fuzy value) of the initial state output, the outputs in all successive states will be stable and fixed to 2V(.33 Fuzzy value) after the initial state . When the output of initial state is 4V(.67 Fuzzy Value) or more then the outputs in all successive states will be stable and fixed to 4V(.67 Fuzzy value)

ii) There are two cases of No Change situation :
When the output of the initial state is 2V or 4V then the output of all states(including the initial state) will remain unchanged. Thus with .67 fuzzy value for the inputs we can obtain no change situation whereas in Boolean based Flip Flops we get this only when both J and K are 0. This clearly points to the diverse range of outcomes of Fuzzy Flip Flops.

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3 CONCLUSION

4 This paper analyses the research work "Non-Associative Fuzzy Flip-Flop with Dual SET-RESET Feature" and reflects a study on Fuzzification of Boolean based flip-flop operations and their dual SET-RESET features. Basically the study and review is objected to explain the formulation of expressions for output of a J-K flip-flop where SET type and RESET type are found to be equivalent. At the end it has been observed that some logic rules are required to be formulated for Fuzzy J-K flip-flop those are applicable both for "SET type" as well as "RESET type" output equations. It is worth noting that the output will be at equilibrium when both J and K are at equilibrium and the output(of next period) are driven by diverse conditions when J and K deviates from equilibrium. Further research can be carried out in this area to incorporate Fuzzy into Boolean based sequential circuit to broaden the variety of output signals so that the Fuzzy enabled circuit can process any hazy value represented by some variations in voltages in the physical level. In this paper firstly the rule base is derived in this paper which may represent various output at diverse input combinations in a well formatted way. Secondly some measure is suggested to avoid the unstable situations arise in different states of Fuzzy J-K Flip Flop. There is a huge scope of further research to resolve the problem of said unstable situation. With the diverse range of outcomes , the Fuzzy Flip Flops brings much broader dimensions in sequential processing as compared to the Boolean based Flip Flops .

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