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SOME PECULIARITIES OF THE SCHMITT TRIGGER

It has been shown that the use of an additional reference voltage at the input of Schmitt inverting and non-inverting triggers and an analog switch at the output increases the accuracy of the threshold and output voltages, regulates the position of the hysteresis curve on the horizontal axis. Hysteresis does not depend on reference voltage. General formulas have been derived for determining the threshold values for inverting and non-inverting triggers, where the two threshold voltages and the two output voltages, depending on the problem setting, can be positive and negative, or unipolar positive or unipolar negative. Those are presented in the form of the sum of stable and unstable components, by increasing the stable component, it is possible to improve the accuracy of threshold voltage values in classical schemes. The necessity of using additional reference voltage is justified. In the proposed scheme, the output parameters of the triggers do not depend on the parameters of the microchip working as a comparator. A guideline of recalculation for increasing the accuracy of threshold voltages using a reference voltage has been developed. A graph is constructed that allows to quickly calculate the relative accuracy increase in the threshold voltages when the reference voltage is applied. This is obtained by increasing the ratio of positive feedback resistances. The reverse problem can also be solved using that graph. New designations of threshold voltages that facilitate the visual understanding of threshold voltage equations have been proposed.

Keywords: Schmitt trigger, analog switch, comparator, threshold voltage, reference voltage, accuracy.

Introduction. The Schmitt trigger is an inverting or non-inverting comparator that converts an input analog signal into a logic signal, depending on the direction of crossing two preselected threshold voltages: high or low. Due to the noise generated on the signal at the moments of overcoming the threshold voltages, the output voltage of the comparator constantly oscillates, accepting its high and low values. To avoid this, hysteresis, which is the difference in threshold voltages, is created by positive feedback. In the reviewed literature, there are various formulas for calculating the input threshold voltages of inverting or non-inverting triggers that operate in a certain voltage range. Different versions of these formulas confuse the user, and the hysteresis curve is placed either in the first quadrant or in all four quadrants simultaneously. The case of two threshold and two output voltages of the triggers being only positive or only negative at the same time is not discussed. The necessity and role of using an additional reference voltage source in increasing the accuracy of the threshold voltages is not discussed either.

Problem setting. Our investigation aims:

1) to find new schematic and technical solutions to increase the accuracy of input and output voltages;

2) to find general formulas applicable to any conditions for inverting and non-inverting triggers and justify their advantages;

3) to justify the need to apply the U_z reference voltage in order to increase the accuracy of the threshold values in classical trigger circuits;

4) to develop a methodological guide for the calculation of the increase in the accuracy of the threshold voltages.

For a workable trigger, such a calculation is considered a direct problem. As a basis, we chose the circuit of the inverting trigger with an analog switch proposed in [1], to which we added a reference voltage U_z. The circuit of non-inverting trigger is also developed in the same way, which is missing in [1]. The constant voltages $U_{out} = U_{out}^1$ and $U_{out} = U_{out}^0$ controlling the hysteresis satisfy only one condition: $U_{out}^1 > U_{out}^0$ (as in the classical circuit) to ensure positive feedback.

As hysteresis control parameters, we have chosen voltages with stable and accurate values such as $U_{out} = U_{out}^1$ and $U_{out} = U_{out}^0$ which must satisfy only one condition: $U_{out}^1 > U_{out}^0$ (as in the classical scheme) to ensure positive feedback. They can be placed on the coordinate plane in three ways:

1) $U_{out}^1 \geq 0$, $U_{out}^0 \leq 0$ (positive and negative voltages).

2) $U_{out}^1 > 0$, $U_{out}^0 \geq 0$ (unipolar positive voltages).

3) $U_{out}^1 \leq 0$, $U_{out}^0 < 0$ (unipolar negative voltages).

In this case, the hysteresis curve is placed in any of 1/4, or 2/4, or 4/4 of the coordinate planes. That is, the two threshold voltages and the two output voltages, depending on the problem setting, can be positive and negative, or unipolar positive, or unipolar negative.

1. Inverting Schmitt trigger. Fig. 1.1 shows the proposed Schmitt trigger with an inverting comparator. The external voltage sources ${U^0}_{out}$ or ${U^1}_{out}$ are applied to the circuit with positive feedback resistors *R1* and *R2* with a switch depending on the magnitude of the input voltage. The analog switch placed at the output of the circuit is logically controlled by a comparator with all possible forms of communication, electrical and non-electrical.

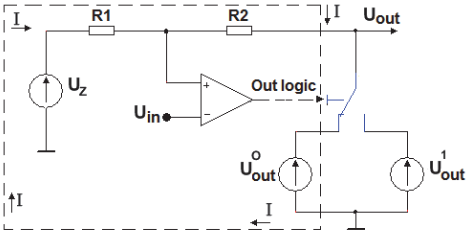

Fig.1.1. The circuit with inverting Schmitt trigger

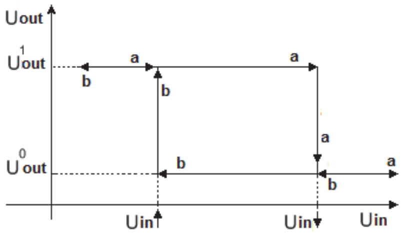

Fig.1.2. The dependence of $U_{out} = f(U_{in})$

Such a circuit also includes the classical form of trigger connection, where *R2* is directly connected to the output of the comparator. In Fig.1.1 *I*-is the contour current flowing through the closed circuit in the direction indicated by the arrow. Fig.1.2 shows the dependence $U_{out} = f(U_{in})$. The point of intersection of the coordinate axes is not specifically indicated because the equations must be of a general form regardless of the position of the hysteresis curve in the plane. Threshold values $U_{in}\downarrow$ and $U_{in}\uparrow$ are indicated on the input voltage U_{in} axis. Such a designation of threshold voltages is introduced to facilitate the visual perception of the input-output functional connection. $U_{in}\downarrow$-indicates that the U_{out}-voltage takes from high U^1_{out}value to low U^0_{out} value and $U_{in}\uparrow$ indicates that U_{out}-voltage takes from low U^0_{out}value to high U^1_{out}value. It can be seen from Fig.1.2 that $U_{in}\uparrow < U_{in}\downarrow$. The hysteresis will be: $\Delta U = U_{in}\downarrow - U_{in}\uparrow$. The dependence $U_{out} = f(U_{in})$ is called the hysteresis curve. It consists of two broken curves: a and b, with a-indicates the increase in voltage U_{in} direction and b-indicates the direction of decrease of U_{in} voltage. At the transition moments the non-inverting input voltage of comparator is equal to the voltage of inverting input: $U_{in} = U_{in}\downarrow$ or $U_{in} = U_{in}\uparrow$. For a closed circuit, from the Kirchhoff's law we have $IR1 + IR2 = U_z - U_{out}$ and $U_{in} = U_z - IR1$. From these equations we can find the threshold voltage U_{in}, assuming that quantities $R1$, $R2$, U_z, U_{out} (*a.* $U_{out} = U^0_{out}$, *b.* $U_{out} = U^1_{out}$) are known, and given in [2]:

$$U_{in} = U_z + (U_{out} - U_z)\,\frac{R1}{R1+R2}. \tag{1.1}$$

From (1.1) we get:

$$U_{in} = \frac{U_z\,R2 + U_{out}\,R1}{R1+R2}. \tag{1.2}$$

This equation is given in [3, 4]. From (1.2) we get:

$$U_{in} = U_z\,\frac{R2}{R1+R2} + U_{out}\,\frac{R1}{R1+R2}. \tag{1.3}$$

Equation (1.3) is a general equation for determining the threshold voltages. Here, the first summation depends only on the U_z component and the $R2/(R1+R2)$

ratio, and the second one-only on the U_{out} component and the $R1/(R1+R2)$ ratio [5, 6]. From equations (1.1), (1.2) and (1.3), only (1.3) shows the dependence of the threshold voltage U_{in} on the voltages U_z and U_{out} separately. Equation (1.3) is applicable to any choice of threshold and output voltages and allows easier selection of U_z and U_{out} voltages. From (1.3), we find the threshold values $U_{in}\uparrow$ and $U_{in}\downarrow$, which are determined by the output voltages of the comparator before the jumping moment: $U_{in}\uparrow$-corresponds to U_{out}^0 voltage, $U_{in}\downarrow$-corresponds to U_{out}^1 voltage [3, 5]:

$$U_{in}\downarrow = U_z\frac{R2}{R1+R2} + U_{out}^1\frac{R1}{R1+R2}\text{ (high threshold),} \tag{1.4}$$

$$U_{in}\uparrow = U_z\frac{R2}{R1+R2} + U_{out}^0\frac{R1}{R1+R2}\text{ (low threshold).} \tag{1.5}$$

From equations (1.4), (1.5) given in [3, 5], it can be seen that the threshold voltages can be located with respect to the constant component $U_zR2/(R1+R2)$ in three ways, depending on the magnitudes and signs of the voltages U_{out}^1 and U_{out}^0. Both thresholds at the same time can be greater than, less than $U_zR2/(R1+R2)$, or placed on both sides of it. The hysteresis will be:

$$\Delta U = (U_{out}^1 - U_{out}^0)\frac{R1}{R1+R2}. \tag{1.6}$$

From (1.6) it can be seen that ΔU does not depend on U_z. This allows the hysteresis curve to shift the along the horizontal axis only by selecting U_z.

If $U_z = 0$, then from (1.4), (1.5) simplified equations are obtained:

$$U_{in}\downarrow = U_{out}^1\frac{R1}{R1+R2}\text{ (high threshold) [1, 7-9],} \tag{1.7}$$

$$U_{in}\uparrow = U_{out}^0\frac{R1}{R1+R2}\text{ (low threshold) [7, 8].} \tag{1.8}$$

In [2-6], U_z-additional reference voltage is applied without justifying the use of it.

Comparator output voltages are often used as output voltages U_{out}^1 and U_{out}^0, which depend on the supply voltage and comparator output voltages, output and load resistances, ambient temperature. The accuracy of the Hysteresis parameters also depends on these parameters. Due to the reference voltage U_z used in the scheme of Fig. 1.1, a stable component appears in equation (1.3). As a result, the influence of unstable U_{out}^1 and U_{out}^0 parameters on threshold voltages and hysteresis parameters is reduced, increasing their accuracy and stability. The proposed solutions were tested with the Multisim program, with classic circuit diagram, and the LM7332 chip. Four combinations of VCC, VEE supply voltages and U_z reference voltage were used: $VCC = 10V$, $VEE = 0V$, $VEE = -10V$, $U_z = 2V$, $U_z = 0V$ and the same $R1 = 2k\Omega$, $R2 = 20k\Omega$ resistors. We considered that $U_{out}^1 =$ VCC, $U_{out}^0 =$ VEE.

In Fig.1.3, the circuit diagram of the comparator with the first combination is shown. In Fig.1.4, the hysteresis curves of the inverting trigger for four combinations is shown, the threshold and reference voltages are given on the x-axis and the output voltages of the comparator on the y-axis for each hysteresis curve separately.

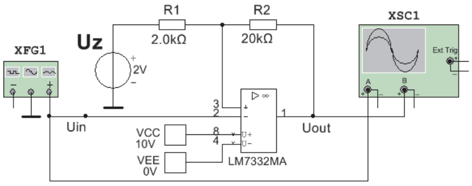

Fig.1.3. The diagram with first combination

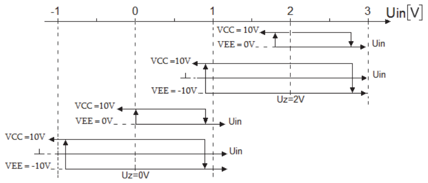

Fig.1.4. Hysteresis curves for four combinations

It can be seen from Fig. 1.4 that by choosing the sign and magnitude of the U_z voltage, the hysteresis curve can be shifted to the range of both positive and negative threshold voltages. When $U_z = 0V$, the circuit is deprived of the ability to easily shift the hysteresis curve.

2. Non-inverting Schmitt trigger. Fig.2.1 shows the proposed circuit of Schmitt trigger with a non-inverting comparator and an analog switch. The switch is logically controlled by a comparator in the same way as in the inverting trigger.

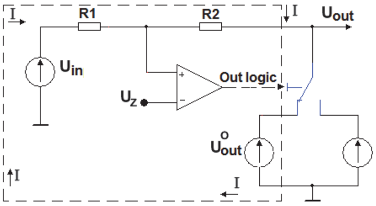

Fig.2.1. The circuit with non-inv. Schmitt trigger

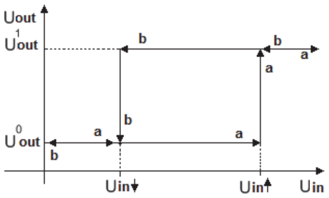

Fig.2.2. The dependence of $U_{out} = f(U_{in})$

Fig.2.2 shows the dependence of $U_{out} = f(U_{in})$. When the input voltage reaches the threshold values $U_{in} \uparrow$ and $U_{in} \downarrow$ indicated on the axis of the input voltage U_{in}, there are jumps in the output voltage: $U_{in} \uparrow$ indicates that the voltage U_{out} from a low value U^0_{out} takes a higher U^1_{out}, value, and $U_{in} \downarrow$ indicates that the voltage U_{out}, starting from a high value U^1_{out}, takes a low value U^0_{out}. Fig.2.2 shows the high threshold for non-inverting trigger $U_{in} \downarrow < U_{in} \uparrow$. Therefore the hysteresis will be: $\Delta U = U_{in} \uparrow - U_{in} \downarrow$. In the transient moments the non-inverting input voltage of the comparator is equal to the inverting input voltage: $U_{in} = U_{in} \downarrow$ or $U_{in} = U_{in}$.

From the Kirchhoff equation for a closed circuit we obtain $U_{in} - IR1 = = U_{out} + +IR2$, where, on both sides of the equation is the voltage of the non-inverting input of the comparator. At the inverting input of the comparator at transient moments, it is equal to the voltage U_z. Let's find the threshold voltage U_{in}, assuming that quantities $R1$, $R2$, U_z, U_{out} (a. $U_{out} = U_{out}^0$, b. $U_{out} = U_{out}^1$) are known [2]:

$$U_{in} = U_z - (U_{out} - U_z)\,\frac{R1}{R2}. \tag{2.1}$$

From (2.1) we get the equations, given in [3] for two thresholds:

$$U_{in} \uparrow = \{(\mathrm{R1} + \mathrm{R2})U_z\ - R1U_{out}^0\}/R2,$$

$$U_{in} \downarrow = \{(\mathrm{R1} + \mathrm{R2})U_z\ - R1U_{out}^1\}/R2. \tag{2.2}$$

From (2.2) we get an equation with separate summables, as in the case of the inverting trigger:

$$U_{in} = U_z \frac{\mathrm{R1+R2}}{\mathrm{R2}} - U_{out}\frac{R1}{R2}. \tag{2.3}$$

Equation (2.3) is a general equation for determining the threshold voltages. Here, the first summation depends only on the U_z component and the $\frac{\mathrm{R1+R2}}{\mathrm{R2}}$ ratio, and the second one-only on the U_{out} component and the $\frac{R1}{R2}$ ratio.

From equations (2.1), (2.2), (2.3), only (2.3) clearly shows the dependence of the threshold voltage U_{in} on the voltages U_z and U_{out} separately. An equation of this form is applicable to any choice of threshold and output voltages and allows easier selection of U_z and U_{out} voltages. From (2.3) let's find the threshold voltages $U_{in} \uparrow$ and $U_{in} \downarrow$, which are determined by the output voltages of the comparator before the jump, $U_{in} \uparrow$-corresponds to U_{out}^0, $U_{in} \downarrow$-corresponds to U_{out}^1:

$$U_{in} \uparrow = U_z \frac{\mathrm{R1+R2}}{\mathrm{R2}} - U_{out}^0\frac{R1}{R2} \text{ (high threshold)}, \tag{2.4}$$

$$U_{in} \downarrow = U_z \frac{\mathrm{R1+R2}}{\mathrm{R2}} - U_{out}^1\frac{R1}{R2} \text{ (low threshold)}. \tag{2.5}$$

The hysteresis will be:

$$\Delta U = (U_{out}^1 - U_{out}^0)\,\frac{R1}{R2}. \tag{2.6}$$

From (2.6) it can be seen that ΔU does not depend on U_z. This allows the hysteresis curve to be shifted by selecting U_z only. If in (3.4) and (3.5) $U_z = 0$, then

$$U_{in} \uparrow = -U_{out}^0\frac{R1}{R2} \text{ (high threshold)}, \tag{2.7}$$

$$U_{in} \downarrow = -U_{out}^1\frac{R1}{R2} \text{ (low threshold)}. \tag{2.8}$$

Equations (2.3), (2.4), (2.5) are missing in the investigated literature, and in [1] are given only equations (2.7) and (2.8).

In the scheme of Fig.2.3 an additional U_z reference voltage source was used to increase the accuracy and stability of $U_{in}\uparrow$, $U_{in}\downarrow$, ΔU parameter values. By reducing the influence of unstable U_{out}^1 and U_{out}^0parameters on threshold voltages and hysteresis parameters, their accuracy and stability increases.

The proposed solutions were tested by the Multisim program, with classic circuit diagram, and the LM7332 chip. Four combinations of supply and reference voltages were used: $VCC = 10V$, $VEE = 0V$, $VEE = -10V$, $U_z = 2V$, $U_z = 0V$ and the same $R1 = 2k\Omega$, $R2 = 20k\Omega$ resistors. We considered that $U_{out}^1 =$ VCC, $U_{out}^0 =$ VEE.

In Fig. 2.3 shows the electric circuit with the first combination.

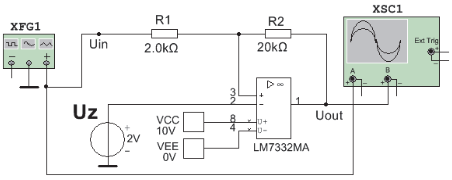

Fig.2.3. The diagram with first combination

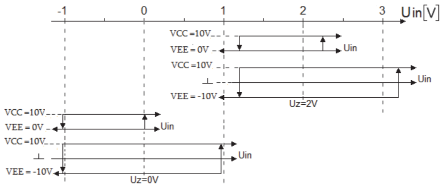

Fig.2.4. Hysteresis curves for four combinations

Fig.2.4 shows the hysteresis curves for all four combinations. In this figure, the threshold and reference voltages are given on the *x*-axis and the output voltages-on the *y*-axis for each curve separately. It can be seen from Fig. 2.4 that by choosing the sign and magnitude of U_z, the hysteresis curve can be shifted to the range of both positive and negative threshold voltages. When $U_z = 0V$, the circuit is deprived of the ability to easily shift the hysteresis curve.

3. The effect of U_z voltage on Schmitt trigger parameters. Let's show that by applying the U_z voltage, it is possible to increase the accuracy of the threshold voltage. For this, in equation (1.3), let's assign: $K = \frac{R2}{R1}$ (feedback coefficient), in this case we get. Let's show that by applying the U_z voltage, it is possible to increase the accuracy of the threshold voltage. For this, in equation (1.3), let's assign: $K = \frac{R2}{R1}$ (feedback coefficient similar to an operational amplifier), we get:

$$U_{in} = U_z \frac{K}{1+K} + U_{out} \frac{1}{1+K}. \tag{3.1}$$

For two thresholds we will have:

$$U_{in} \downarrow = U_z \frac{K}{1+K} + U_{out}^1 \frac{1}{1+K} \text{ (high threshold)}, \tag{3.2}$$

$$U_{in}\uparrow= U_z\frac{K}{1+K} + U_{out}^0\frac{1}{1+K} \text{ (low threshold).} \tag{3.3}$$

Let's consider that the resistors used in the circuit and the additional reference voltage, have very high accuracy and stability. When $U_z = 0V$, the threshold voltage $U_{in} = U_{out}\frac{1}{1+K}$ depends only on the output voltage, therefore the relative volatility of its value is as much as the volatility of U_{out}. When using U_z-reference voltage, the instability of the voltage U_{in} depends only on the second component-U_{out}. By choosing the magnitude of the stable component to be much larger than the magnitude of the unstable component, the effect of the transient voltage U_{out} on U_{in} will be much smaller than it would be in the absence of U_z. For this it is necessary:

1) when $U_z = 0V$, with (3.2) and (3.3) the calculate the values of the high and low threshold voltages for a certain value $K1 = \frac{R2}{R1}$;

2) to estimate their percentage changes depending on the output voltage changes,

3) as a threshold requiring a stable value, to choose either the high or the low threshold and consider its value unchanged;

4) in order to soften the unstable component of the threshold voltage selected in (1.3) to the necessary extent, to select a new larger value of K ($K2 = \frac{R2}{R1}$);

5) from (3.2) or (3.3) to calculate the necessary U_z voltage, that will provide the selected threshold voltage;

6) to recalculate the new value of the other unknown threshold having the voltage U_z.

Using equations (3.2) and (3.3), let's show the necessity and features of applying U_z-reference voltage with example of a circuit with bipolar power supply. The following initial parameters are given: $U_{out}^1 = 10V$, $U_{out}^0 = -10V$, $U_z = 0V$, $K1 = 9$, voltage error: +10%, permissible error of threshold voltage: 1%. By carrying out steps 1-4 of the guide, we choose $K2 = 99$ and complete the calculation. The results are presented in the Table below.

The same method is used to calculate in the case of a non-inverting trigger. In cases where the changes in the second threshold voltage and hysteresis, due to the use of the classic scheme are not satisfactory, the circuits with the analog switch given in Fig. 1.1 and Fig. 2.1 should be used. A partial solution can be the use of a bidirectional, parametric stabilizer of the output voltage in a classical circuit.

Table

Calculations results of initial and final values of the threshold voltages and their errors

Initial data without ref. voltage				Calculation data		Initial data for recalculation				Recalculation data	
${U^1}_{out}$	${U^0}_{out}$	U_z	*K1*	$U_{in}\downarrow$	$U_{in}\uparrow$	${U^1}_{out}$	${U^0}_{out}$	U_z	*K2*	$U_{in}\downarrow$	$U_{in}\uparrow$
+10*V* +11*V*	-10*V* -11*V*	0*V* 0*V*	9 9	1*V* 1.1*V*	-1*V* -1,1*V*	+10*V* +11V	-10*V* -11*V*	0,909V 0,909*V*	99 99	1*V* 1,0099*V*	0,7999*V* 0,7899*V*
10%err	10%err	-	-	10%err	10%err	10%*err*	10%err	0%err	-	1%err	1,25%err

Using equations (3.2) and (3.3), let's calculate the dependence of the threshold voltage change on the output voltage change, when applying U_z.

The change in the threshold voltage is directly proportional to the change in the output voltage: $\Delta U_{in} = \Delta U_{out}\frac{1}{1+K}$. Assume the ratio of the threshold voltage change (ΔU_{in}) and the output voltage change (ΔU_{out}) is $A = \frac{\Delta U_{in}}{\Delta U_{out}} = \frac{1}{1+K}$.

$A1 = \frac{1}{1+K1}$, where $K1 = \frac{R2}{R1}$ (first feedback coefficient), when $U_z = 0V$,

$A2 = \frac{1}{1+K2}$, where $K2 = \frac{R2}{R1}$ (new feedback coefficient), when $U_z \neq 0V$.

Let's calculate the accuracy coefficient, $N = \frac{A1}{A2}$, which shows how many times the accuracy of the threshold voltage increases when the reference voltage U_z is applied, or how many times the error depending on ΔU_{out} decreases. $N = \frac{A1}{A2} = \frac{1+K2}{1+K1}$.

Let's assume that $K2 = nK1$, then

$$N = \frac{1+nK1}{1+K1} = \frac{1}{1+K1} + n\,\frac{K1}{1+K1}. \qquad (3.4)$$

This is a linear equation or graph as a function of *n* for fixed values of $K1$, where *n*-indicates how many times the initial $K1$ coefficient must be increased in order to increase the accuracy of the threshold voltage by the necessary *N*-times.

In equation (3.4) n shows how many times the initial $K1$ coefficient should be increased in order to increase the accuracy of the threshold voltage by the necessary *N* –times. In Fig.3.1, the table on the basis of which the graph of Fig.3.2 is constructed. The table is constructed for several fixed values of $K1$ and n (a-point and b-points) calculated using equation (3.4). For any value of $K1$, when $n = 1$, the set of lines $N = f(n)$ intersects at the point $N = n = 1$ (Fig. 3.2, point *a*), when $K1 \gg 1$, then $N \approx n$. This graph allows to calculate the amount of increase (*N)* in the relative accuracy of the threshold voltages when applying U_z, which is obtained when the ratio $\frac{R2}{R1}$ is increased *n*-times. Using the graph, it is also possible to solve the opposite problem. For this, *N* must be calculated, having in advance the numbers $A1$ and $A2$ (the resulting and permissible error sizes). Then, using *N* and the known curve $K1$, the required *n* must be found.

	a		b	
K1	n	N	n	N
1	1	1	12	6,5
2	1	1	10	7
3	1	1	9	7
5	1	1	10	8,5
10	1	1	12	11
>>10	1	1	12	12

Fig.3.1. Calculation data

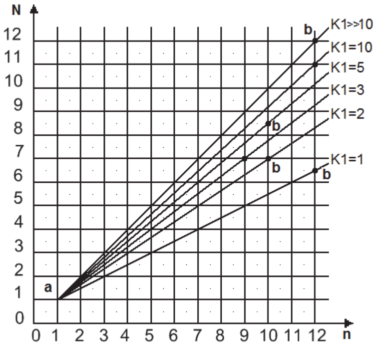

Fig.3.2. Graph of the function N=f(n)

Conclusion. It is shown that the use of an additional reference voltage at the input of inverting and non-inverting triggers, and an analog switch at the output increases the accuracy of the threshold and output voltages, adjusts the position of the hysteresis curve on the (horizontal) axis of the input voltage. The magnitude of the hysteresis does not depend on U_Z. It is shown that threshold and output voltages of the triggers do not depend on the supply and output voltages of the microcircuit used.

The use of general formulas (1.3) and (2.3) for determining the threshold voltages of triggers under any conditions presented as the sum of stable and unstable components is justified. The need to use additional reference voltage in triggers is justified. By increasing the dose of the stable $\boldsymbol{U_Z}$ component in equations (1.3) and (2.3), the accuracy of the threshold voltages in classical circuits can be increased. It is shown that the hysteresis curve can be placed in any 1/4, or 2/4, or 4/4 of the coordinate plane. That is, the two threshold voltages and the two output voltages, depending on the problem setting, can be positive and negative, or unipolar positive, or unipolar negative.

A guideline of recalculation for increasing the accuracy of threshold voltages using a reference voltage is developed. The calculation process by example of the inverting trigger is shown.

An accuracy increase factor-*N*, showing how many times the accuracy of the threshold voltage increases when applying the reference voltage is introduced. It is shown that (3.4) is a linear equation depending on n: $N = f(n)$. The graph of this dependence, where n shows how many times the initial K1 coefficient of positive feedback should be increased in order to increase the accuracy of the threshold voltage by the necessary N-times is built. The opposite problem is also solved with the same graph.

With the proposed designations of threshold voltages, it is possible to determine what kind of trigger is used in the comparator scheme: inverting or non-inverting. They facilitate the visual understanding of threshold voltage equations.

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ՇՄԻՏՏԻ ՏՐԻԳԵՐԻ ՈՐՈՇ ԱՌԱՆՁՆԱՀԱՏԿՈՒԹՅՈՒՆՆԵՐԻ ՄԱՍԻՆ

Ցույց է տրվել, որ Շմիտտի շրջող և չշրջող տրիգերների մուտքում լրացուցիչ հենակային լարման, իսկ ելքում անալոգային փոխանջատիչի օգտագործումը մեծացնում է երկու շեմային և երկու ելքային լարումների ճշտությունը, կարգավորում է հիստերեզիսի կորի դիրքը մուտքային լարման առանցքի վրա: Հիստերեզիսը կախված չէ հենակային լարումից: Ցույց է տրվել, որ շեմային և ելքային լարումները կախված չեն օգտագործվող միկրոսխեմայի սնուցման և ելքային լարումներից: Հիմնավորվել է ցանկացած պայմանների դեպքում տրիգերների շեմային լարումների որոշման ընդհանուր բանաձևերի կիրառումը, որոնք ներկայացվել են կայուն և անկայուն բաղադրիչների գումարի տեսքով: Հիմնավորված է տրիգերներում լրացուցիչ հենակային լարման օգտագործման անհրաժեշտությունը: Ընդհանուր հավասարումներում կայուն բաղադրիչի չափաբաժինը մեծացնելիս դասական սխեմաներում մեծանում է շեմային լարումների ճշտությունը: Ցույց է տրվել, որ հիստերեզիսի կորը կարող է տեղաբաշխվել կոորդինատային հարթության ցանկացած մեկ քառորդում կամ երկու քառորդում, կամ չորս քառորդում, իսկ շեմային երկու լարումներն ու ելքային երկու լարումները կարող են լինել դրական և բացասական, կամ միաբևեռ դրական, կամ միաբևեռ բացասական: Մշակվել է հենակային լարման կիրառմամբ շեմային լարումների ճշտության բարձրացման վերահաշվարկի ուղեցույց: Շրջող տրիգերի օրինակով ցույց է տրվել հաշվարկի ընթացքը: Ներմուծվել է ճշտության մեծացման գործակից, որը ցույց է տալիս, թե քանի անգամ է ավելանում շեմային լարման ճշտությունը հենակային լարման կիրառման ժամանակ: Նրա միջոցով կառուցվել է գրաֆիկ, որն օգտագործվում է շեմային լարումների հարաբերական ճշտությունը՝ անհրաժեշտ չափով մեծացնելու համար կատարվող հաշվարկների ժամանակ: Նույն գրաֆիկի միջոցով լուծվում է նաև հակառակ խնդիրը: Առաջարկվել են շեմային լարումների նոր նշանակումներ, որոնք հեշտացնում են շեմային լարման հավասարումների տեսողական ընկալումը:

Առանցքային բառեր. Շմիտտի տրիգեր, անալոգային փոխանջատիչ, կոմպարատոր, շեմային լարում, հենակային լարում, ճշտություն:

С.Г. МАРТИРОСЯН, Дж.Э. ТОРИКЯН

О НЕКОТОРЫХ ОСОБЕННОСТЯХ ТРИГГЕРА ШМИТТА

Показано, что при использовании дополнительного опорного напряжения на входе инвертирующего и неинвертирующего триггеров Шмитта и аналогового ключа на выходе повышается точность двух пороговых и двух выходных напряжений, корректируется положение кривой гистерезиса на оси входного напряжения. Гистерезис не зависит от опорного напряжения. Установлено, что пороговое напряжение и выходное напряжение не зависят от питающего и выходного напряжений используемой микросхемы. Обосновано использование общих формул для определения пороговых напряжений триггеров при любых условиях, которые представлены в виде суммы стабильной и нестабильной составляющих. Обоснована также необходимость использования дополнительного опорного напряжения в триггерах. При увеличении доли стабильной составляющей в общих уравнениях в классических схемах возрастает точность определения пороговых напряжений. Показано, что кривую гистерезиса можно расположить в любом одном квадранте, или двух, или четырех квадрантах координатной плоскости, а два пороговых напряжения и два выходных напряжения могут быть положительными и отрицательными, либо однополярными положительными или однополярными отрицательными. Разработано руководство по пересчету для повышения точности пороговых напряжений с использованием опорного напряжения. Процесс расчета показан на примере инвертирующего триггера. Введен коэффициент увеличения точности, который показывает, во сколько раз увеличивается точность порогового напряжения при приложении опорного напряжения. С его помощью построен график, который используется при расчетах для повышения относительной точности пороговых напряжений. Противоположная задача решается с помощью того же графика. Предложены новые обозначения пороговых напряжений, с помощью которых можно определить, какой триггер используется в схеме компаратора: инвертирующий или неинвертирующий. Они облегчают визуальное понимание уравнений пороговых напряжений.

***Ключевые слова*:** триггер Шмитта, аналоговый ключ, компаратор, пороговое напряжение, опорное напряжение, точность.