VP Bericht - Elektronik D

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***Abstract*—The here presented experiments give a brief overview of some important properties of digital circuits, how to measure them and is therefore a good starting point for those, that want to understand how digital circuits work. Problems of designing an own circuit are highlighted and solutions are presented. The importance of understanding the used digital components is emphasized.**

CONTENTS

I. INTRODUCTION

In this experiment, some of the basic concepts of digital circuits are explored. Digital circuits contain logic gate. The gates transform a digital input signal into some digital output signal following a well defined functionality. The input and output signal are either “high/1” or “low/0”. This is a main difference compared to the analogous circuits, which have a continuous range of input/output signals. In today’s world gates play an important role in. Every digital circuit contains a few up to multiple billions of them.

TODO: Write something about IC.

Gates can be categorized by gate-family, that they belong to (e.g. TTL or CMOS) and some other specific properties. Gates perform different operations to “compute” the output signal based on some input signal. Also, gates differ in terms of propagation delay, which is the delay a change in one of the input signals takes to cause a change in the output signal. The propagation delay is very important when designing digital circuits.

In the following, the performed experiments are presented. The experiments describe how to determine the operation performed by a digital circuit and it’s propagation delay, how a pulse generator is build and how to implement a very simple bit shifter logic.

II. EXPERIMENT: SIMPLE LOGIC GATE

A. Samples and measurement setup

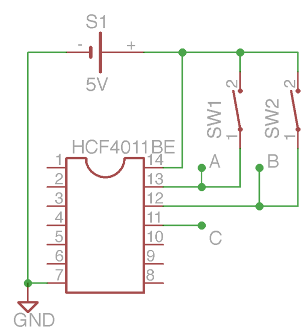


Fig. 1: Circuit diagram to measure truth table.

The circuit was setup as shown in figure 1. Based on the different input signals at A and B, different values for the output signal C were measured using a oscilloscope. As for the ICs, a HCF4001BE and HCF4011BE were used.

To measure the propagation delay, input signal A was connect to a square wave voltage generator. Input signal B was connected to ground. The IC HCF4001BE was used for this measurement. The voltage of the generator was set to 2.9V and the frequency to 1Hz. The input signal A and output signal C was visualized using a oscilloscope. The oscilloscope’s trigger signal was connected to the voltage generator.

B. Results

For different input signals A and B, the truth-table was measured as shown in table 2.

The propagation delay was measured to be around 50ns as seen in figure 3.

4011			4001		
A	B	C	A	B	C
0	0	1	0	0	1
0	1	1	0	1	0
1	0	1	1	0	0
1	1	0	1	1	0

Fig. 2: Truth table measuring IC HCF40011BE and HCF4001BE

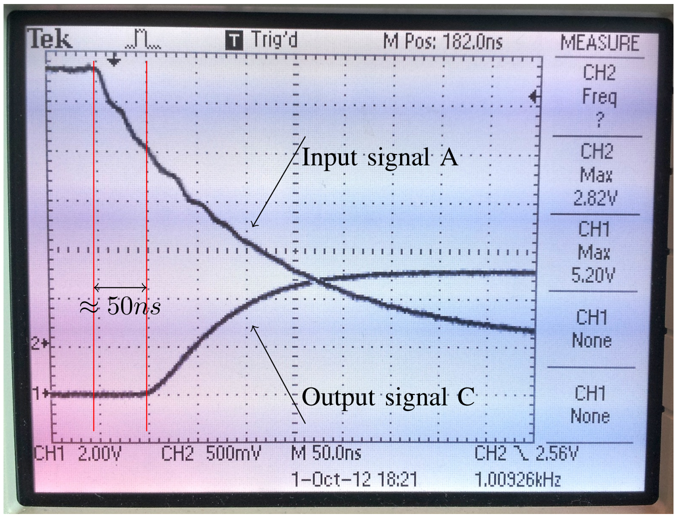


Fig. 3: Propagation delay measurement.

C. Analysis and Discussion

Based on the measurements, the IC HCF4001BE seems to be a logic NOR gate, whereas the IC HCF4011BE seems to function as a NAND gate. This fits with the specified functionality of the gates.

Looking up the propagation delay from the data sheet, it is said to be typically around 40ns and up to 75ns. This fits with the here measured delay.

III. Experiment: Pulse Generator

A pulse generators are used to create rectangular, periodic voltage signals. In this experiment, such a generator was build and its properties examined.

A. Samples and measurement setup

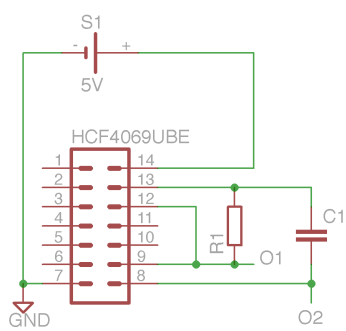


Fig. 4: Circuit diagram of astable multivibrator.

The circuit was assembled as shown in figure 4. Here, the IC HCF4069UBE was used, which contains six NOT gates. The voltage difference between the output signals $O1$, $O2$ and the ground was quantified using an oscilloscope. This also allowed to visualize and measure the period of the oscillations. Different values for the resistance $R1$ and the capacity $C1$ were chosen and the resulting period of the voltage signals determined.

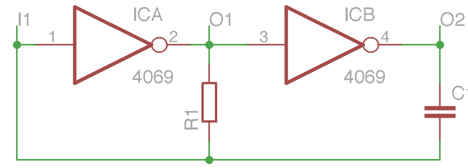


Fig. 5: schematic drawing of the astable multivibrator circuit.

B. Functionality explanation

A schematic drawing of the circuit is presented in figure 5. The explanation follows the one given in [BOOK]. Let's assume the voltage at $O1$ is set to be *high* and the capacitor is uncharged. Due to the *high* signal at $O1$, the signal at $O2$ is *low*. Over the resistance $R1$ the capacitor is charged. At some point, the voltage at $I1$ is high enough, such that the input signal of ICA is recognized as *high*. This causes the signal at $O1$ to become *low* and therefore the signal at $O2$ to be *high*. The charged capacitor discharges, which keeps the *high* signal at the $I1$ input for some time until the voltage on the capacitor is to low, such that the signal at $I1$ is recognized as a *low* signal, the signal at $O1$ becomes a *high* one and things start over again.

C. Results

The time diagram for the voltage at $O1$ and $O2$ is visualized in figure 6. In table 7 different period times t due to different choices of resistance R and capacity C are listed. The values for the resistances and the capacities shown here are excluding a manufacturing error of roughly up to 10%. Some of the capacities were more precise measured and are listed in the $C*$ column.

D. Analysis and Discussion

The k-value is defined as

$$k = \frac{t}{R \cdot C} \tag{1}$$

where t is the period time, R is the resistance of the resistor R *and* C *is the capacity of the capacitor* C. Based on the measurements, the k-values are computed in table 7 in the k column. For the more precisely measured capacities $C*$, the k-value $k*$ was computed using the $C*$ value.

As mentioned in [BOOK], the relation between t and the other quantities is given by

$$t = 2\ R\ C\ \ln(3) \approx 2.2\ R\ C \tag{2}$$

which gives the value of k using equation (1) as

$$k = 2\ \ln(3) \approx 2.2 \tag{3}$$

The average values of k and $k*$ given in table 7 match very well with the expected values for k. Using the standard derivation of the average as an indicator for the uncertainty of the here measured k and $k*$ values, the literal value is within the range of average +- standard derivation. However,

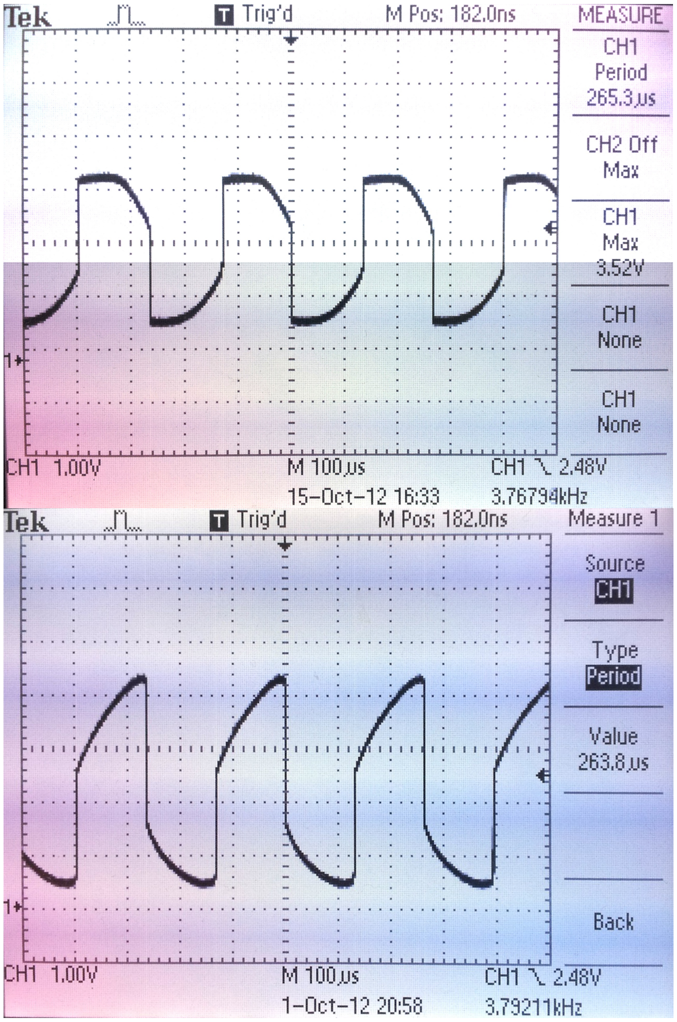


Fig. 6: Up: Voltage difference at O1, bottom: Voltage difference at O2. Both as function of time.

R [kOm]	C [nF]	C* [nF]	t [us]	k [s/(Om F)]	k* [s/(Om F)	Lit – <k*>
1.0	56	59.7	178	3.18	2.98	
1.0	100	90	265	2.65	2.94	
1.0	220	216	638	2.90	2.95	0.76
1.0	1000		2788	2.79		
1.8	56	59.7	288	2.86	2.68	
1.8	100	90	430	2.39	2.65	
1.8	220	216	1040	2.63	2.67	0.48
1.8	1000		4600	2.56		
3.3	56	59.7	468	2.53	2.38	
3.3	100	90	700	2.12	2.36	
3.3	220	216	1690	2.33	2.37	0.17
3.3	1000		7700	2.33		
39.0	1000		69760	1.79		
47.0	220	216	19600	1.90	1.93	-0.27
120.0	220	216	47520	1.80	1.83	-0.36
120.0	1000		212200	1.77		
150.0	220	216	58370	1.77	1.80	-0.40
*) = Corrected			Average:	2.37	2.46	
			Std. Deriv.:	0.45	0.43	

Fig. 7: Measurement of period time t as function of resistance R and capacity C.

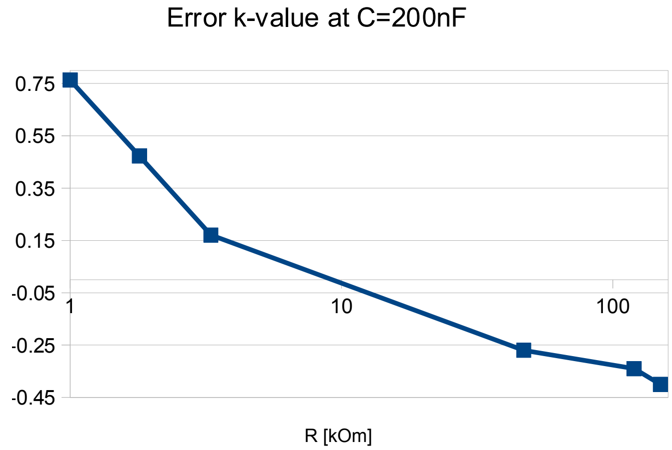


Fig. 8: Measurement of period time t as function of resistance R and capacity C.

the standard derivation is larger then 1/10 of the average value. This indicates a high uncertainty in the measured quantities.

The last column $Lit - k*$ holds the difference between the literature value (3) and the calculated $k*$ value and therefore a simple error estimation between measurement and literature value. The error is calculated for the same capacitor $C = 200\text{nF}$. A plot of these errors is shown in figure 8. The X-axis is plotted logarithmically. The shape of the curve suggests a exponential relation between R and the error. As the $k*$ values are roughly the same for different choices of C, this might be an indication, that the error is mostly related to the choice of the resistance. The reason for this correspondence remained unclear to the author.

IV. Experiment: Self Build Digital Circuit

In the last experiment, a shift operation was designed and implemented. For simplicity, the shifter presented is made up of only two input signals and zero or one shift to the left. Written as a programming expression, this corresponds to:

$$\{0, 1, 2, 3\} << \{0, 1\} \tag{4}$$

where the numbers in brackets represent all possible values. The result of the calculation was made visible to the user by using three LEDs.

A. Samples and measurement setup

To get an idea how the circuit should setup, the required logical operations were determined as:

$$\begin{aligned} \text{LED1} &= \text{I1} \wedge \neg S \\ \text{LED2} &= (\text{I2} \wedge \neg S) \vee (I1 \wedge S) \\ \text{LED3} &= (\text{I2} \wedge S) \end{aligned} \tag{5}$$

where $I1$, $I2$ are the two input signal for the number to shift (the number is represented in binary form), S indicates if a shift should happen (if high, do a shift on the input $I1$, $I2$) and LED$\{$1,2,3$\}$ are the LEDs showing the result of the operation.

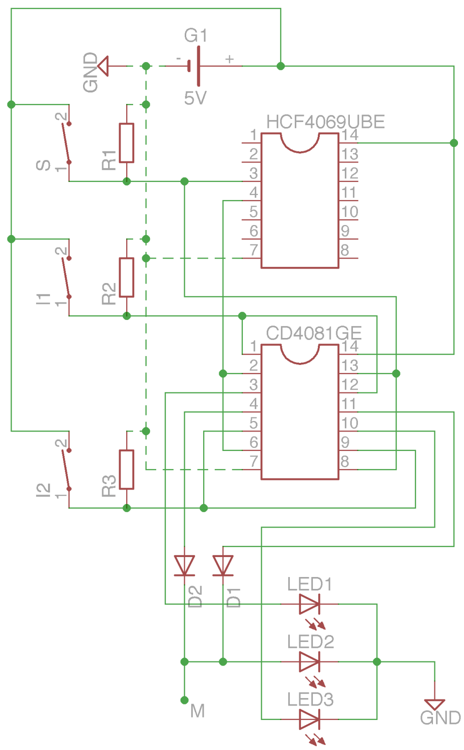


Fig. 9: Scheme of the shifter circuit.

After looking up the required components, the circuit was sketched out as shown in figure 9. The four AND operations were covered using the IC CD4081GE, the NOT operation using the IC HCF4069UBE, the OR operation was done by "just" connecting two wires. The reasoning for the components R{1, 2, 3} and D{1, 2} is provided in the following section.

To determine the propagation delay, input S was connected to a square wave generator running at 1khz and 5V. The input I2 was opened/set to a "low" signal and the I1 input was closed/set to a "high" signal. The voltage difference at LED2 compared to GND was measured by attaching an oscilloscope to M.

B. Results

The output signals of the AND gates was oscillating. The LED2 was shining only very little.

After fixing these issues (see next section), the signal as meassured at the output M is shown in figure 10.

C. Analysis and Discussion

The oscillation of the AND gate output signal was due to not well set "low" signal on the inputs. The first draft missed out the resistors R{1, 2, 3}. It was assumed, that no input signal at a gate input results in a "low" signal. For the here used AND gates, the "low" signal needed to be explicit connected to the ground. By using the resistors, the "high" signal for closed switches was detected by the gates, but at the same time for opened switches, the wire was set to a "low" signal. The resistors were chosen to be 100Ω. The choice of 18Ω worked as well, but the resistors got very hot and therefore got replaced by the 100Ω ones.

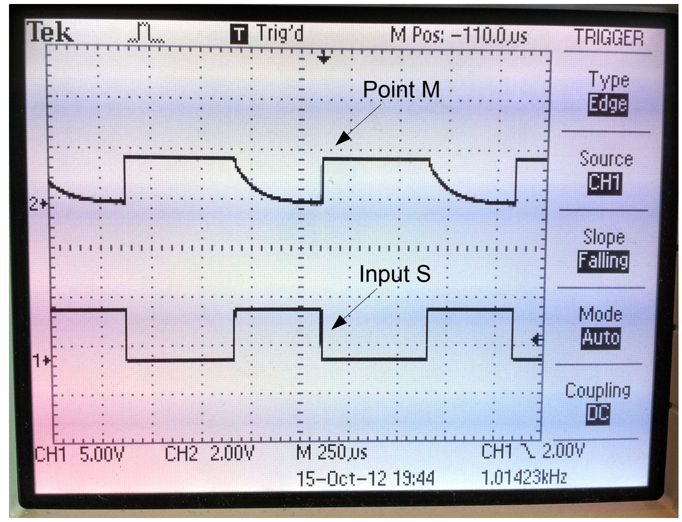


Fig. 10: Voltage difference at Point M and Input S compared to GND using D1=1N4148PH

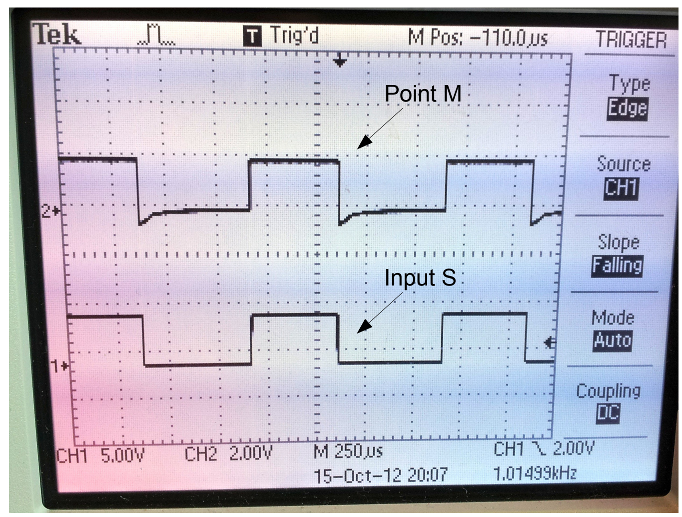


Fig. 11: Voltage difference at Point M and Input S compared to GND using D1=1N40058912

"Just" connecting the wires for LED2 turned also out to be a bad idea. A "high" signal at one of the wires was attenuate by the "low" signal of the other wire. Therefore, the two diodes D1 and D2 were added. This made the LED2 shine much brighter.

With these two changes, the shifter was operating as expected.

The waveform in figure 10 at point M was not expected. It looks like a discharge curve seen in a resistor-capacity circuit. However, the shifter circuit doesn't have "any" capacities. Replacing the diode D1 with a wire, made the wave become rectangular. This indicated a relation between the unexpected wave shape and the used diode.

The initially used diodes were of the type 1N4148PH. Replacing D1 with the type 1N40058912 changed the waveform's shape as seen in figure 11.

Trying to understand this behavior, a simplified model was created as displayed in figure 12. The model reduces the LED

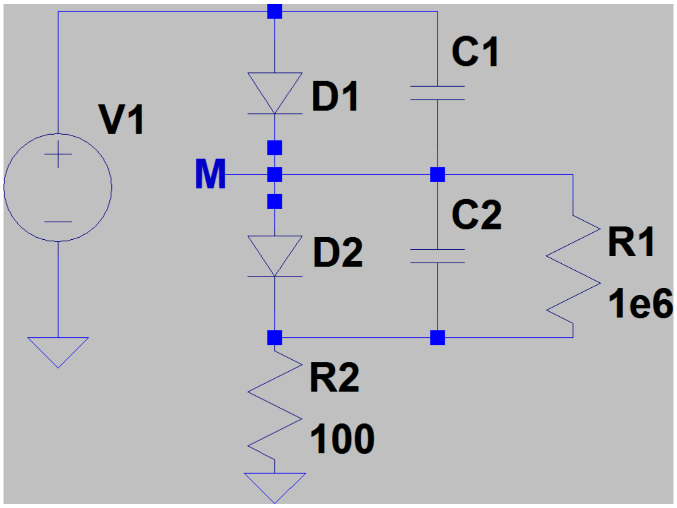
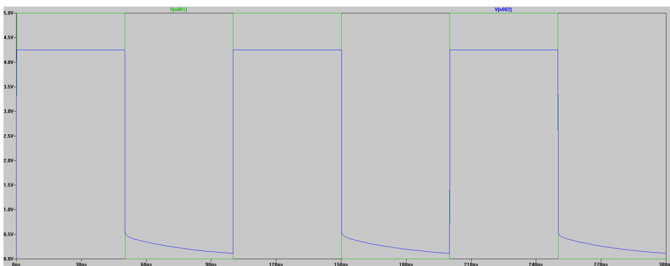
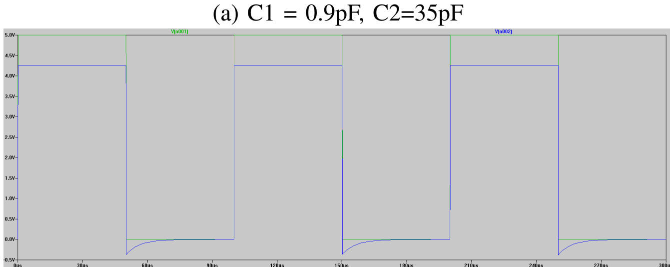


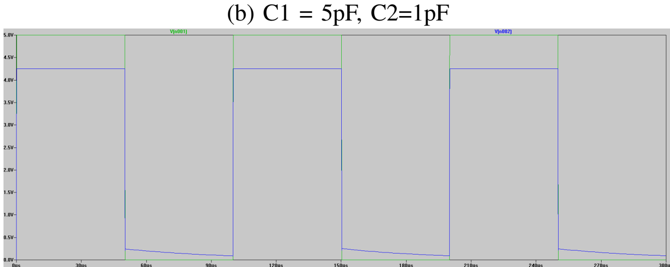
Fig. 12: Reduced circuit used for simulation.



(a) C1 = 0.9pF, C2=35pF



(b) C1 = 5pF, C2=1pF



(c) C1 = 15pF, C2=35pF

Fig. 13: Result running simulation for different choices of C1 and C2. Green curve: voltage of generator, blue curve: voltage at M; both compared to GND

to a diode. Every diode has a small inner-capacity with the order of pF. These capacities are added explicit in this model. The oscilloscope used to measure the voltage difference has itself a resistance of 1MΩ, which was included in the model as well. For different choices of the the capacity C1 and C2 the circuit was simulated and the results are shown in figure 13.

Type	Capacity
1N4148PH	0.9pF
1N40058912	15pF
LED (LTL-307GE)	35pF

Fig. 14: Used components and their capacities.

Looking at the used components' capacities as listed in figure 14, the first and the last simulation is match the used components. While the first simulation curve matches the shape of the measured curve in figure 10, the last simulation doesn't match the observed curve in figure 11; but this measurement fits very well for the made-up capacities used in the middle simulation. The reason for this mismatch was not able to be figured out by the author.

Without adjusting the diodes D1 and D2, a rectangular wave was possible to achieve by connecting M to GND using a resistor with 10kΩ. This follows the same idea as the resistors introduced at S, I1 and I2.

V. Conclusion

The experiments presented here show some important property of digital circuits and how to measure those. Moreover, by doing a circuit from scratch, some of the issues designing a digital circuit were enlightened. Constructing a circuit requires understanding all the components. Otherwise things like the inner-capacity of diodes or the resistance of the measurement equipment might be forgotten to be taken into account. These can lead to unexpected behavior, which were relatively simple to figure out in this setup, but are imagined to be hard to control on larger circuits.

Given that the here implemented circuit was simple compared to the circuits shipping with a computer/smartphone, it can only be imagined the hard work it takes to make large circuits operate precise. The complexity even grows, as there are more and more components packed on each chip and more functionality is covered by the same gadget.

References

[BOOK] U. Tietze, C. Schenk *Halbleiter-Schaltungstechnik*. Springer, sechste, neue Überarbeitete und erweiterte Auflage (1983), pp 176-177