Foreword

As in recent years, Conrad Electronics again has a new calendar in 2016, also, with 24 experiments for December 1 through 24. The topic is digital electronics. The experiments deal with digital counters with the CMOS chip 4060. This IC contains 14 digital divider flip-flops as well as a clock oscillator with multifaceted uses. It enables very different and very versatile applications that are not only educational but also fun. At the end there is a circuit that can be hung on the Christmas tree to represent a wood fire and falling stars.

There are various ways to use the electronics calendar. One person might simply wish to build everything exactly according to plan and enjoy the success; another wants to understand it exactly. The experiment descriptions should satisfy both. For this reason, the construction and the function are always described only as briefly as necessary for the successful construction. Afterwards, the technical background is explained in brief. Thus one finds the key ways with which one can also go on to look for more information. In any case, the experiments provide the greatest pleasure when one works on them with others. Parents and grandparents can perhaps pass on valuable experience and pique the interest of children and youths.

Using the available parts, one can also build significantly more circuits than can be shown here. Someone who works through the presented experiments with interest will quickly find further circuit variants and similar applications. And completely new circuits can also be developed. No limits are placed on your ingenuity!

We wish you great fun and a happy Christmastide!

1 The LED test

The first test in Advent should cause an LED to light up. An LED must never be connected directly to a power source; one always needs a series resistor as well. Without this resistance, the LED would be destroyed by too much current! The LED must be installed in the correct direction. It has two different connections. The short wire is the negative terminal (cathode C); the longer wire is the positive terminal (anode A). The wider lower edge is flattened on the cathode side. Also, on all LEDs in this calendar, the larger bracket inside the LED is connected to the cathode.

Behind the first door, you will find a red LED and a resistor that matches it. You will also need a 9-V block battery. The first test must be carried out especially carefully. Attention: avoid looking directly into a lighted LED from short distances of less than one meter. Bright LEDs can cause retinal damage. Avoid having both LED contacts ever touch the battery terminals at the same time! The resistor must always be connected in series; otherwise, the LED burns through. Hold both components to the battery as shown in the diagram. The LED lights up brightly.

One presents electronic circuits clearly in circuit diagrams. There is a symbol for each component. The LED consists of a triangle for the anode and a straight line for the cathode. That signifies the current direction. Two short arrows pointing outward stand for the light that is emitted. The resistor is shown as a rectangular box. Every resistor has a specific resistance value. In this case, it is 10,000 ohms = 10 kilo-ohms (10 kΩ, in the circuit diagram 10 k for short). The actual component is marked with coloured bands (brown, black, orange for 10,000 and gold for potential deviations up to +/-5%).

The circuit diagram shows a series circuit. The current runs through the battery, resistor and LED. In this case, the resistor has the task of limiting the amperage to a useful value. The higher the resistance, the smaller the amperage. At 10 kΩ, the LED is in fact operated far below its maximum permitted current, but it already lights up sufficiently brightly.

2 Battery connection

The second door hides a battery clip for the 9-V battery. Rebuild the test from the first day, but somewhat differently. Use the battery clip and make sure that the black connection wire is the negative terminal and the red the positive terminal. It is imperative that you avoid short-circuiting the battery, that is, creating a direct connection between the two terminals. In the case of a short, the battery could become very hot, and if the short lasts for a longer time, in extreme cases the battery could even explode. Plus, short circuits reduce the lifespan of the battery.

The resistance 10 kΩ determines the current through the LED. In this case, one can assume that about 2 V are applied to the LED, thus another 7 V at the resistor. The result is a current of only 0.7 mA. For comparison: LEDs are mostly designed for currents of 20 mA. This red LED, however, begins to generate significantly visible light even with less than 1 mA.

3 Plug design

Open the third door and take a breadboard out of the compartment. This device makes it easier to design complicated circuits. The breadboard, with a total of 270 contacts in the 2.54-mm grid (0.1 in), provides a secure connection of the components.

The plug field has 230 contacts in the middle area, each of which is connected conductively through vertical strips with five contacts. In addition, there are 40 at the edge for the power supply; these consist of two horizontal contact spring strips with 20 contacts each. The plug field thus has two independent supply rails, which are used here for the positive and negative terminals of the battery.

Inserting components requires a relatively large amount of strength. The connection wires thus bend over easily. It is important that the wires be inserted exactly from above. A pair of tweezers or a small pair of pliers helps in this process. A wire is grasped as short a distance above the breadboard as possible and pushed downward vertically. In this way, even sensitive connection wires like the tin-plated ends of the battery clip can be inserted without bending.

Construct the circuit from the first test yet again on the breadboard. Again, you are building a series circuit with resistance and LED. The circuit diagram shows the precise circuitry, but with a slightly different arrangement of the components, which is as similar as possible to the actual test.

4 Lamp switch

Behind the fourth door, you will find the wire necessary for all following tests. Build an LED lamp with switch contact. Cut a suitable piece of wire, 4 cm in length, and strip the insulation from the ends to a length of about 5 mm. This wire should be installed as connection to the LED. A shorter wire, 2 cm long, is installed as strain relief to protect the weak connection wires. The battery clip should always remain connected so that the connections do not wear down too much.

The simple switch consists of two bare pieces of wire that touch together only when pushed together with the finger. For this purpose, cut two pieces of wire, 2 cm long, and remove the insulation completely.

5 A protective diode

You will find another red LED behind Door Number 5. Install this second LED in the circuit. The direction must be correct for this; otherwise, no current will flow. If everything has been put together correctly, both LEDs light up. And although two LEDs are now in series, the brightness of the first LED remains practically the same.

The new LED has an important function for the following tests. It serves as a protective diode and should prevent an incorrect polarity of the battery. The component to be installed tomorrow, in particular, reacts very sensitively to an incorrect polarity and should be protected against potential faults. At the same time, the LED is a simple current indicator, with which one can recognize the correct function of a circuit.

6 Digital circuit

Open Door Number 6. Behind it you will find the most important part of this calendar, the CMOS-IC 4060. This IC with 16 pins contains a total of 14 divider flip-flops and a multifaceted oscillator circuit. The connections 1 and 16 are on the left side and are marked with a groove. An additional note is offered by the label, which one can read on the lower row (Pin 1 to Pin 8). Before the first use of the IC, the connections must be aligned to be parallel because they still stand a bit too far to the outside after the production. Push all pins on one side at the same time on a hard table surface to align them sufficiently. Then place the IC correctly on the breadboard. Attention: if it is inserted the wrong way round, the connections 8 (GND, negative) and 16 (VCC, positive) are switched, so that the operating voltage is connected with the wrong polarity and the IC is destroyed. In this case, even the protective diode at the positive terminal does not help, since it protects only against a battery that is connected the wrong way round.

The first test uses a portion of the oscillator circuit at the connections 10 and 11. The input OSC1 is placed at GND (negative terminal, logical zero). At the output OSC2 is the LED with its series resistor. If everything has been assembled correctly, the LED lights up. The IC thus has the voltage switched on at the output (logical one) and thereby inverts the input status. For most of the tests with the 4060, the reset input (RES) must also be attached at GND. The red LED at the VCC connection indicates the operating current and protects the IC. If everything is correct, both LEDs light up with the same brightness.

7 An open input

Open the seventh door and take out a resistor. It has 22 MΩ (22 mega-ohms, red, red, blue) and is repeatedly used in the following tests in the oscillator circuit. The resistor is connected at the input OSC1 only on one side. One thus has an "open input". It is undefined whether one or zero is present; the LED is either on or off. The result is random and can be affected by bringing your finger close to it. Even at a distance of a few centimetres, the status of the gate can change. Static charges and the electrical fields connected with them are responsible for this change.

You can turn the output on or off by tapping briefly on the input with your finger. If it is switched on, both LEDs light up; if it is switched off, both LEDs can be off. The IC then consumes virtually no power. However, there can be circumstances in which the output is indeed still switched off, but the IC nevertheless consumes a certain amount of power. That is the case when the input voltage is neither exactly zero nor exactly at the operating voltage but is somehow between these voltages. As long as the input is touched, a half brightness can also be adjusted, whereby the LEDs actually flash very rapidly. This lies in the 50-Hz AC fields of the electrical grid, which have the effect that your own body conducts a small alternating current.

8 Feedback

Behind Door Number 8 you will find a 10 kΩ resistor (brown, black, orange). This time, it is used as protective resistance at the input of the IC. The 22-MΩ resistor connects the second output to the input of the oscillator circuit. The LED is either on or off; the result is unpredictable. An existing status lasts for a random length of time. You can change the status, however, if you hold the free connection at the input once at the positive and once at the negative. Beyond that, you can with some luck switch the LED on or off if you simply tap the resistor with your finger or touch it with a piece of wire that you hold in your hand.

In this circuit, two inverters are placed in series. An input zero state becomes a one state after the first inverter and goes back to zero after the second inverter. Through the feedback, therefore, the zero state is maintained at the input as well. Conversely, a one status at the output appears as one again and persists. However, if the input is brought to the other state even very briefly, the circuit turns over. A random impulse often suffices for this purpose, which occurs when you touch it because you are electrically charged. This kind of circuit is also called a trigger circuit or a flip-flop. At the same time, therefore, the circuit is also a digital memory with a storage size of 1 bit. If you take the right LED at the output OSC3 out of the circuit, the circuit is practically de-energized even in the one state. The left LED is thus permanently off regardless. Only in the switch-over moment does current flow. If you touch the input, the left LED can light up.

9 An LED flasher

Behind the ninth door, you will find a ceramic disk capacitor with the capacity 100 nF. The label reads 104 and stands for 100,000 pF (picofarads), thus 100 nF (nanofarads). The capacitor allows you to build an oscillator, that is, a circuit that automatically switches the state repeatedly. In this case, a slow flashing light occurs. This time, the high-ohmic resistor with 22 MΩ lies between OSC1 and OSC2 and forms a negative feedback. The 10 kΩ resistor, together with the 100 nF capacitor, forms the feedback.

The speed of the switch-over is determined primarily by the 100 nF capacitor and the 22 MΩ resistor. Both components together have a time constant of 0.1 µF * 22 MΩ = 2.2 s. And in fact, each stable state lasts about two seconds. In one minute, therefore, the output is on approximately 15 times and off 15 times. If you touch both connections of the 22-MΩ resistor with your finger, you connect your body's resistance in the scale of 1 MΩ in parallel and thereby reduce the time constant. The more firmly you hold onto the wires, the faster the flashing will be.

At the protective LED, one can see that current begins to flow in each case even before the switch-over into the on state. This is a sign that medium voltages are present at the input. Even if you remove the right LED from the output, you can see the regular increase of the current.

10 Fast flickering

Behind Door Number 10 you will find a 100 kΩ resistor (brown, black, yellow). It should now replace the previous 22 MΩ resistor in the oscillator circuit. The flashing thus becomes so fast that it appears to be a steady light. However, if you move the entire circuit back and forth, you will see lighted stretches with interruptions. One can achieve the same effect by observing the layout in a moving mirror.

This time, the time constant is 100 kΩ * 100 nF = 10 ms. The output is on for 10 ms and off for 10 ms. The result is a total period of 20 ms and a frequency of 50 Hz, thus in the scale of the mains frequency. One can still recognize up to 16 Hz as flickering. Above that, one mostly sees only a steady light.

11 Divider through 16

A 10 nF capacitor (labelled 103) is hiding behind the eleventh door. It receives an auxiliary function and lies between the positive and negative terminals of the battery. This is a standard measure in all digital circuits and helps to avoid transient signals. The oscillator is converted back to a low frequency, and the second LED is now connected to a series resistor at the output Q4. The LED switches between roughly 30 s on and 30 s off.

Differently from before, the IC now connects directly to the battery. Because everything has functioned properly so far, you can now take a chance on experimenting even without polarity protection. The second LED is thus free for the actual test and shows the distributed frequency. Between the oscillator and Q4, there are four divider steps that divide the frequency of the clock signal respectively by two. Thus, 16 clock pulses add up to one output impulse. The elementary period is four seconds at the oscillator and about one minute at the output Q4.

12 Counter from zero to three

Behind the twelfth door is another 10 kΩ resistor (brown, black, orange), which is placed in the oscillator. The frequency is indeed increased again to around 50 Hz, but this time an LED is placed at the output Q5, which divides the clock signal by 32. At the two LEDs, one therefore sees one faster and one slower flashing. Both signals together can be read as a 2-bit binary number.

The counter thus constantly counts from zero to three. Then it runs over and continues with zero. Observed more closely, the LEDs display multiples of 8, that is, 0, 8, 16, and 24 input pulses of the oscillator. The first three divider steps act as pre-scaler by 8 and deliver a clock signal of around 6 Hz, which can still be easily followed with the eye. If you would like to see the counter more slowly, you can insert the 22-MΩ resistor in the circuit. The counter state then switches roughly in the period of half-minutes, so that one has built a simple digital clock.

13 Three-bit counter to seven

Behind Door Number 13 you will find a yellow LED. With this addition, the counter should be expanded to three bits. There are now a total of eight different counter states between 000 (zero) and 111 (seven). The two red LEDs at the outputs Q5 and Q6 share a joint series resistor. The flashing with the lowest frequency occurs at Q6.

A resistance for two LEDs is possible but leads to a special effect. The red LED at Q6 displays two brightness levels. As long as Q5 and Q6 are switched on, the current distributes itself through the series resistor to two LEDs. In the first tests, relatively high LED series resistors of 10 kΩ were deliberately used. One thereby achieves only an adequate brightness and can experiment without being blinded. Plus, this circuitry saves energy so that the battery will last as long as possible to the end of the testing.

14 Three-four time

Behind the 14th door you will find another 10 kΩ resistor (brown, black, orange). It is now installed between VCC and RES. In addition, two LEDs are placed from Q5 and Q6 to the reset input. But watch out: this time the cathodes are placed at the outputs. The result is a very special blinker that takes on three states – flashing in three-four time!

Until now, input pulses could be divided only by two. Divisor ratios of 16, 32, 64, etc. are thus possible, up to a maximum of 16,384 at output Q14. But when one uses the reset input and additional diodes, almost any divisor you desire can be achieved. A resistor attempts to increase the reset input. But the connected diodes keep the voltage low as long as at least one of the outputs used is at zero. In this case, the counter runs until Q5 and Q6 are switched on. Then a reset occurs immediately, and the counter is reset to zero. For the two outputs, that means that only possible states occur: 00, 01 and 10. Thus a divisor by three arises. With this method, you can also achieve almost any divisor ratios you desire. With two diodes, for example, you can create a divisor by 5 or by 9.

15 Stopped counter

The 15th door reveals a push-button switch. Pay attention to the installation direction. The switch contact always lies between two adjacent pins. The button is now used to stop the oscillator. A counter with three outputs recognizes eight different states. The task now is to stop the counter always exactly in the moment when all three LEDs are on.

This time the smaller 10 nF capacitor is used in the oscillator. The frequency is thus ten times higher and the task is correspondingly harder. When closed, the push-button switch applies the full operating voltage to the oscillator input and thereby prevents further oscillations. As soon as the contact is opened, the oscillator starts again.

16 High-speed dice

Behind Door Number 16 you will find a 4.7 kΩ resistor (yellow, violet, red). The oscillator is now converted again and should be so fast that one can no longer distinguish the individual flash pattern. The result is then truly random chance – as with an actual die. When one presses the button, the die stops in one of eight possible states. Differently from an actual die, the states 000 (zero) and 111 (seven) must not be counted. All other results stand for the numbers 1 to 6. In rolling the die, therefore, one can also learn the binary counting system at the same time:

1 = 001b, 2 = 010b, 3 = 011b, 4 = 100b, 5 = 101b, 6 = 110b

An oscillator without the capacitor, that may be puzzling at first. Actually, however, there is a very small capacitor present. Two adjacent contact strips of the breadboard form a capacitor with about 4 pF (4 picofarads). With the 22 MΩ resistor, the result is thereby a pulse frequency of about 5 kHz. At Q6, the frequency, divided by 64, appears at around 80 Hz. The human eye can no longer follow this fast change. The oscillator becomes even faster with a resistance of 100 kΩ. It oscillates then at around 600 kHz and has a marked effect even on a nearby medium-wave radio. The oscillator of the CD4060 functions with the components of the calendar in a vast range between 0.25 Hz and 600 kHz. In addition, you can usually generate a precise 50-Hz cycle by directly touching the input. In this test, the result is that the blink pattern is run through significantly more slowly.

17 Light sensor

Another yellow LED is hiding behind Door Number 17. Both yellow LEDs together should now form a light sensor. If a lot of light falls on the yellow LEDs, one receives a fast flickering of the red LEDs. In the dark, the flashing becomes very slow.

The oscillator works again with the extremely small capacitor of two contacts of the breadboard. Thus, even with a high resistance of 22 MΩ, a high frequency results. The two yellow LEDs form a resistor that is much higher still, however, yet one that is dependent on the ambient brightness. Both LEDs are connected in series such that one of the two always operates in the back direction. Thus, there should actually not be any current flowing. However, when light falls on the LED crystal, the LED acts like a photodiode. Now a small amount of current flows even in the back direction. The more light falls on the LEDs, the larger this current is, and the higher the oscillator frequency becomes.

18 Button counter

Behind the 18th door you will find a 4.7 kΩ resistor (yellow, violet, red). With it, another LED can now be operated with greater brightness. In all, four LEDs create four bits of a binary number. Therefore, 16 numbers between 0 and 15 can be represented. But this time the counter does not run by itself; instead, the pulse is generated by the push-button switch.

After every eight button presses, a level change should be observable at Q4. Actually, however, the change is significantly more frequent. In most cases, it takes three or four button presses for a change at the outputs. This is due to the contact bounce of the switch, where the contacts bounce back multiple times on closing. Thus, with one push, one generates a short series of impulses, which are all counted.

19 Debouncing the button

Door Number 19 reveals a 2.2 kΩ resistor (red, red, red). With it, you have a further resistor for a greater brightness. The significant change to the test consists in an additional capacitor parallel to the input OSC1. It serves to debounce the button. Thus, with each button press, exactly one pulse is now counted. After every eight pulses, the output Q4 changes. And after every 128 pulses, the counter returns to its starting state. One thus has an reliable event counter.

The 4060 can count pulses that are shorter than one microsecond. The 100 nF capacitor, together with the 10 kΩ resistor, has a time constant of one millisecond, which is a thousand times longer. That is thus how long it takes for the capacitor to discharge after the contact opens. However, since the contact bounce is significantly faster, the counter always recognizes only one pulse. This reliable 4-bit counter can also represent larger numbers if one uses the higher-valued outputs. In all, it takes 16,384 button presses for all outputs, including Q14, to return to their starting state.

20 Multi-flash pattern

Open Door Number 20 and take out a 1 kΩ resistor (brown, black, red). With it, you have the series resistor suitable for maximum brightness. This time, very special flash patterns should result. Each of the yellow LEDs flashes four times in a row and then pauses while the other LED flashes. The two red LEDs each flash once and then pause longer.

The special flash pattern occurs because the LEDs conduct current in only one direction. The lower yellow LED lights up only when Q7 is already switched off and Q4 is already on. Thus, one can create very different patterns with LEDs at additional outputs. At any rate, it is permitted in this case to connect LEDs even without resistors directly between two outputs. At an operating voltage of 9 V, the output transistors of the 4060 have an on resistance of about 300 Ω. Thus, both outputs together have a resistance of 600 Ω. The result is an LED current of around 10 mA, which is still significantly below the permitted 20 mA.

21 Four brightness levels

You will find an especially bright green LED behind Door Number 21. In this test, it should become brighter by stages. There are four brightness levels, 0, 1, 2 and 3, which run in sequence. The red LED shows the pulse at the same time.

The circuit corresponds in function to a digital-analogue converter, which converts digital numbers into analogue voltages or currents. Q7 switches a large current through the 1-kΩ resistor on and off. A large brightness level results. In addition, Q6 switches a smaller current through the 2.2-kΩ resistor on and off, which adds to the larger current. The result is thus a total of four brightness levels.

22 Colour flasher

Behind Door Number 22, a 100 μF (microfarad) electrolytic capacitor appears. It has a thousand times greater capacity than the 100 nF disk capacitor you have used up to now. One thus achieves large charging currents that can be seen as LED light flashes. Here green and yellow light flashes occur in a longer interval. Each flash gradually subsides in about half a second. So that one does not have to wait too long for the flashes, the smaller 10 nF capacitor is installed in the oscillator. The red LED shows the divided pulse signal.

When using an electrolytic capacitor, the installation direction must be observed. The negative terminal is marked with a white stripe. If one applies a current to the electrolytic capacitor the wrong way round for a long time, it can be destroyed and in the worst case even burst. Here the positive terminal is placed at Q12, where the voltage is alternately +9 V and 0 V. Two LEDs must be connected in the back direction so that the electrolytic capacitor can alternately charge and discharge.

23 Four-way flashing light

Behind the 23rd door you will find a white LED. Four LEDs should now flash in sequence such that two LEDs are never on at the same time. Despite that, only two counter outputs are used for this test. The outputs Q12 and Q13 generate very slow changes. So that it does not take too long, the oscillator is again set to a higher clock frequency with the smaller 10 nF capacitor.

The circuit forms a 1-of-4 decoder, which decodes single states from four possible binary numbers at two outputs. Normally, one needs additional logical circuits for this purpose, but none are available here. The circuit functions only with a trick and relies on the fact that the different LEDs operate at different voltages. The red LEDs light up with less than 1.8 V; by contrast, the green and the white LED require significantly more than 2 V. When Q13 is switched on, the 10-kΩ series resistor supplies power for the green LED. However, if Q12 is in the zero state at the same time, the red LED is practically parallel to the green LED and draws current away from it because of the lower LED voltage. Q12 thus determines whether the green or the lower red LED lights up. In the one state of Q13, by contrast, either the white or the upper red LED lights.

24 Firelight and falling stars

Behind the last door you will find another 1 kΩ resistor (brown, black, red). It is used for a festive light that can be used to decorate the Christmas tree at the end of the experiments. Two red and two yellow LEDs stand for a wood fire, which generates a relatively constant light and flickers only slightly. Sometimes, however, a falling star lights up the night for a brief moment, represented by a green or a white LED.

The base brightness of the red and yellow LEDs is predetermined by two 1 kΩ resistors. Larger resistors with 4.7 kΩ and 10 kΩ switch smaller currents from various counter outputs to the LEDs and provide for a slight and seemingly irregular flickering. It has a calming effect and is also nice to look at for a long time. The infrequently occurring light flashes are generated with output Q10 and a 100 μF electrolytic capacitor. It is easy to make changes. Experiment with other counter outputs and different resistors and make a Christmas light that is entirely your own.

Appendix

Components in the calendar:

1 red LED + 10 kΩ resistor

2 Battery clip

3 Breadboard

4 Wire

5 Red LED

6 CD4060

7 22 MΩ resistor

8 10 kΩ resistor

9 100 nF capacitor

10 100 kΩ resistor

11 10 nF capacitor

12 10 kΩ resistor

13 Yellow LED

14 10 kΩ resistor

15 Push-button switch

16 4.7 kΩ resistor

17 Yellow LED

18 4.7 kΩ resistor

19 2.2 kΩ resistor

20 1 kΩ resistor

21 Green LED

22 100 μF electrolytic capacitor

23 White LED

24 1 kΩ resistor