

# Energy Economy using LED Multiplexing

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**Abstract.** This work is based on use of LED multiplexing. With this technique, it is possible to use a smaller number of pins of a microcontroller to energize the same number of LED. We explored the retinal persistence. It is a physiological property of the human eye. Due to this property, the human eye retains the captured image on the retina during a short time interval. Using the retinal persistence, it is possible to use multiplexing techniques to minimize the number of the microcontroller pins used and the energy consumed by the circuit. Instead of using multiplexing to switch the power among different displays, multiplexing was used also among the seven segments of a single display. Next, we combined more than one display on the same circuit. A prototype was developed and achieved up to 65% energy savings without perceptible loss of display quality.

## I. Introduction

Seven segment displays (called just "displays" throughout this article) are very common for electronic product to display numerical output. Many common devices like calculators, watches, electronic weighing scales, ovens and many other household items use them. You must have also seen lifts display the current floor numbers in seven segment displays. In many applications, the LEDs must be driven with intelligent control circuitry. According to the task at hand, this control circuitry must be able to fulfill various functions and tasks. In the following pages, we provided a solution that explores the retinal persistence, energy economy and reduction of the number of I/O pins required by PIC microcontroller.

The persistence of the image, also known as retinal persistence or retinal retention, is a property of human eye that "holds" the captured image on the retina during a short time interval. This property is perceived when the eye is exposed to a light source and then is exposed to total darkness. The light that penetrates the retina is recorded and takes some time to disappear [1]. This persistence of the image on the retina allows the fusion of intermittent images [2]. The perception of the images is not instantaneous. A latency period is necessary - for each color - for the image to be captured. However, this period is approximately compensated by retinal retention [3]. The duration of image persistence on the retina is approximately 1/24 second. Thus, if the excitation on the retina are made at shorter intervals, each image overlaps with the previous one, being combined, giving us an idea of continuity.

The seven segments of a display are driven individually through separate I/O pins of the microcontroller. For four seven segment LEDs displays, 28 I/O pins will be required, which is quite a bit of resources and is not affordable by many microcontrollers. That's why when more than one display is used, a multiplexing technique is used to minimize the required number of microcontroller pins.

Another advantage of multiplexing is the energy savings. If the multiplexing technique is implemented in a lighting circuit (LED, for example), we can alternate the power cyclically between its components. If the time settings are done properly, it can be given to the human observer the impression that all LEDs are always lit, although this is not actually happening. This will result in significant energy savings.

Energy conservation has advantages if observed in at least two respects. In a broad view, if we combine the huge number of displays and LEDs present in many devices, a partial economy in each

will lead to great savings when combined. This will bring a positive impact, since the power generation has impacts on the environment. In an individual vision of autonomous and/or embedded systems, most of the time they have power consumption constraints. This system, are usually powered by batteries or by alternative energy sources such as photovoltaic cells, among others. Thus, energy economy can contribute to extending the useful life of the systems, delaying the need to replace or recharge the batteries.

For this project, we started with four seven-segment LEDs digits multiplexed, meaning that only one digit is lit at one time. This produces a very rapid flickering in the digits, because the active digit is rapidly switched back and forth. But more than that, in this project, instead of applying the multiplexing among different displays, it was applied in multiplexing all segments of each display, combined with display multiplexing.

A prototype was built. With it, we made qualitative evaluation of digits displayed in various situations. We also made energy consumption measurements and compared these measurements with a multiplexing scheme made only among displays.

## II. Multiplexing individual segments

It is usually found in the literature, tutorials and manuals, the LED multiplexing made among different displays. In this scheme, each display is lit at a certain moment and this occurs cyclically among all circuit displays. This scheme provides the economy of pins and energy desired.

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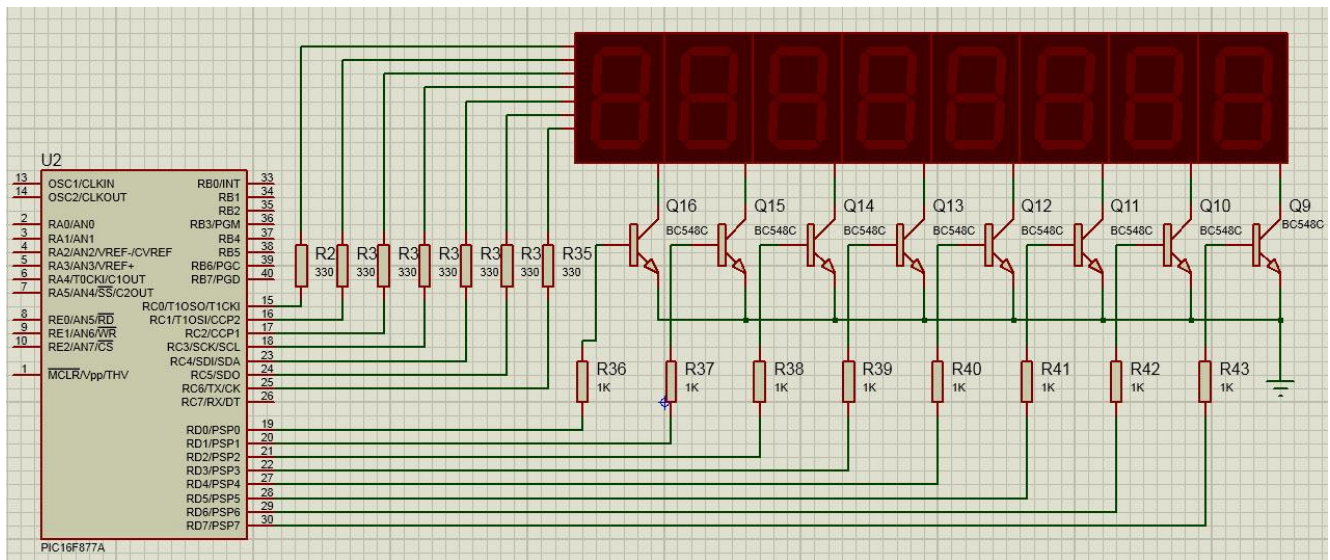


Fig. 1 – Multiplexing Circuit

In this work, we have developed a prototype that implements multiplexing among all segments of all displays, combined.

Shown in Fig. 1 is the multiplexing of 8 common cathode type seven segment LED displays with a PIC16F877A microcontroller. The seven segments are connected to PORTC through current limiting resistors R29 to R35 (330 kohms). A particular segment is active when the corresponding PORTC pin is right. However, it will not glow until its cathode is connected to ground. The cathodes of the eight LED displays are not directly connected to ground. Instead, 8 NPN transistors are used as switches to connect or disconnect the cathode terminals from ground. When the base of the transistor is low, the transistor conducts and corresponding digit's common cathode is connected to ground. Therefore, the transistor selects which display is active. The conduction of the transistors is controlled by RD0 through RD7 pins of PORTD.

Thus, while PORTD implements the multiplexing among displays, PORTC implements multiplexing among each segment of each display, as you can see in Fig. 2. During the time interval in which a given display is enabled, there is another multiplexing cycle among the segments of the display, and so forth.

Note that, since only one segment of a particular display is energized at a given time, there is a reduction in the current in the microcontroller PORTC. Thus, the transistors Q9 to Q16 could be suppressed by adjusting the value of the resistors. That was not implemented in the circuit because it was used to compare the two multiplexing methods (with and without segment multiplexing).

Regarding the hardware, the architecture proposed in this paper has no significant differences relating to displays multiplexing. The main difference is the software that controls the process.

In each hardware interrupt, the software checks which display is enabled (standard multiplexing). For the enabled display in that time, other multiplexing loop starts, scanning each of the segments. Thus, cyclically, each segment is energized during a period of time which is enough to record the light at retina, or to be noticed as illuminated by the human eye.

An multiplexing optimization has been introduced in order to scan only the lit segments. The proposed algorithm skips the segment that is not part of the digit to be displayed saving time and energy. Thus, the complete display scanning cycle will spend a minimum of time only for those lit segments in each display. This scheme improves the image quality noticed by the human eye.

Fig. 3 shows the prototype multiplexing algorithm core. In the following lines we present some comments about it.

The interrupt( ) function is called every time the microcontroller generates an interrupt. Although the prototype handles other interruptions, the one that is relevant at this time is the timer interrupt specified in row 2 of the code. In lines 4 and 5 you can see one function that allow the microcontroller timer be adjusted by potentiometer prototype.

In line 6 of this code we can deal with two modes of circuit multiplexing. The "menu1" refers to standard multiplexing and "menu2" refers to the two levels multiplexing described in this article.

Standard multiplexing is described from line 7 to 12, this procedure goes through each display circuit lighting simultaneously all the necessary segments of the enabled display.

From line 15 on, the segments multiplexing is performed at the enabled display. The program skips the segments turned off. The "while" condition perform this task, going forward immediately. In this case, there is one loop iteration without any segment being lit.

It is important to note that when all segments of the enabled display were covered, the program execution flow goes directly to the next display (lines 17-26).

When the loop is over, it means that a segment to be lit was found. Then, the data is sent to the PORTC and PORTD and the software is awaiting the next interrupt.

Fig. 4 illustrates the prototype that was built. The seven segments displays are connected at the top; LEDs on the left show the multiplexing operation mode (displays multiplexing or segments multiplexing); the buttons set, down left, allow you to select the operating mode between the two forms of multiplexing (center button), set the number of displays that will lit (right and left) and the

number that will be displayed (up and down); in the down center terminals (POT), is connected a potentiometer that controls the multiplexing timing.

### III. Results

In tests with the prototype, we obtained the following results:

\* With up to 3 displays running the hybrid multiplexing scheme we obtained 100% quality of the display digits visualization, this being equivalent to the standard multiplexing scheme.

\* With 4 displays in operation, a quality decline is observed on the display digits visualization, but the system is still efficient.

\* From 5 displays on, the system is not useful, occurring a very large drop in the quality of the displayed digits.

In all cases above, we made several tests, including worst case tests, which corresponds to the presence of the digit 8 in all displays.

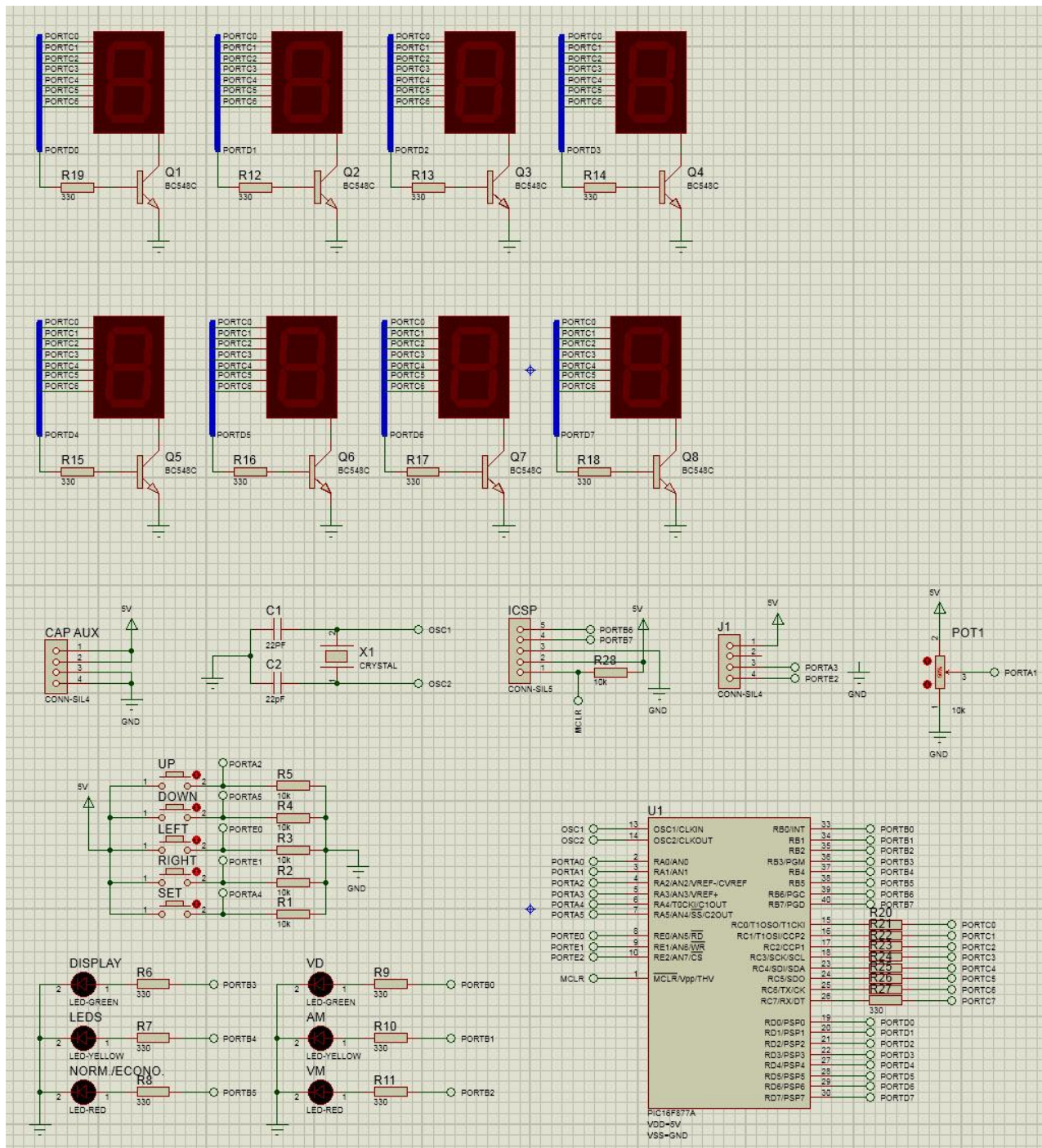


Fig. 2 – Detailed circuit

```

1 void interrupt () {
2     if (TMR1IF bit == 1) {
3         TMR1IF bit = 0;
4         TMR1L = 0x00;
5         TMR1H = tempH;
6         if (menu == 1 || menu == 2) {
7             if (menu == 1) {
8                 PORTD = disps[disp];
9                 PORTC = nums[n_disp];
10                disp++;
11                if (disp > (n_disps - 1))
12                    disp = 0;
13            } else {
14                seq++;
15                while ((nums[n_disp] & seqs[seq]) == 0) {
16                    seq++;
17                    if (seq > 7) {
18                        seq = 0;
19                        constr++;
20                        if (constr >= max_constr) {
21                            constr = 0;
22                            disp++;
23                            if (disp > (n_disps - 1))
24                                disp = 0;
25                        }
26                    }
27                }
28                PORTD = disps[disp];
29                PORTC = nums[n_disp] & seqs[seq];
30            }
31        }
32    }
33 }
34
35

```

Fig. 3 - Prototype multiplexing algorithm core

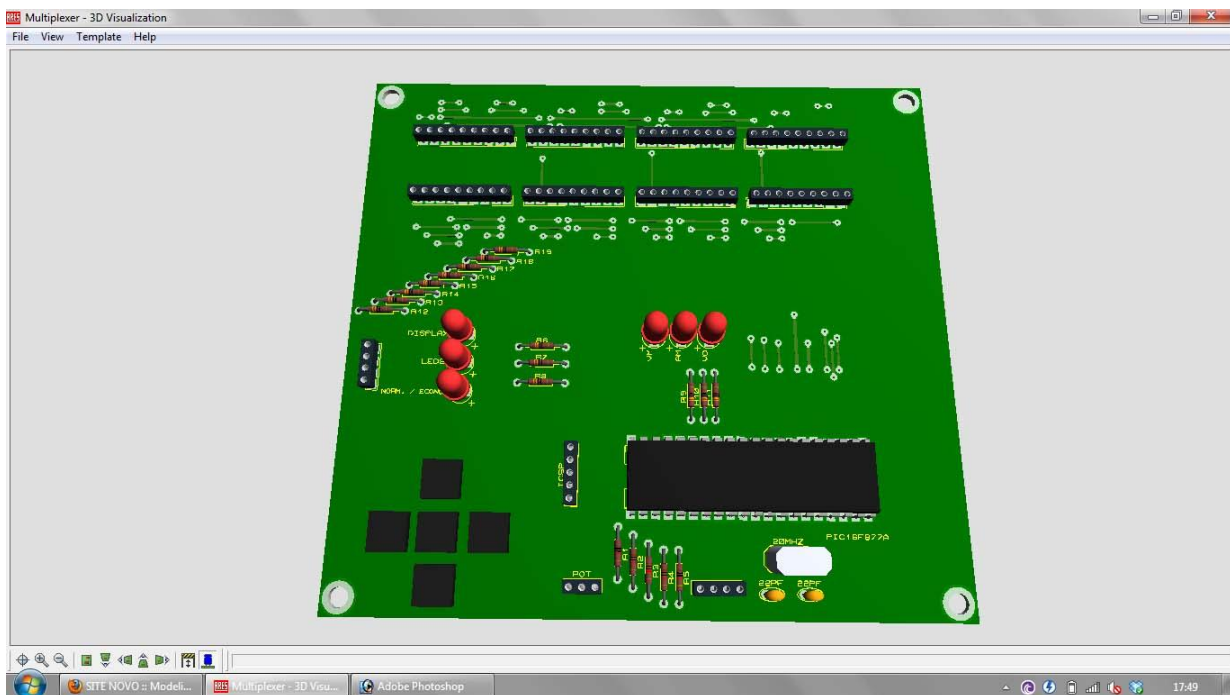


Fig. 4 – Prototype desing



Fig. 5 – Working Prototype

## IV. Energy efficiency

During testing, circuit power consumption measurements were made in both conditions, standard multiplexing and two levels multiplexing (displays and segments). In both cases, it was measured the current in the displays and in the rest of the circuit. It was observed that the energy consumption in the rest of the circuit is constant in both cases.

In the worst case (8 digit display), the average value of the electric current measured in the displays was 50.5 mA for standard multiplexing and 17.5 mA for the scheme proposed in this paper. It corresponds to approximately 65% energy saving. In the case of random digits, the measurements showed lower levels of economy, reaching 10% for displaying only the digit 1.

### Conclusions and future work

The multiplexing scheme presented in this paper has been validated by tests and measurements made on a prototype. The results showed the technical feasibility of the scheme, energy efficiency and the quality achieved in view of the digits on the display.

The working prototype can be seen in Fig. 5.

As future work, we intend to explore the ability of LEDs have to withstand an overload current at short time intervals. By exploring this feature, we want to light up each segment

in a shorter time interval, applying an overcurrent. Thus, the multiplexing cycle is reduced, enabling operation over 4 displays.

### Acknowledgment

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