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Comparison of Signal Switching Matrices for Remote Laboratories and a Novel Solution using FPGA Technology

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Abstract

The concept of signal switching matrices in the field of remote laboratory systems is presented in this paper. Existing solutions for this problem are reviewed and a novel approach using FPGA technology is proposed. The FPGA implementation method is described in details and compared to the existing solutions in terms of implementation costs, surface requirements, universality, and feasibility. It is shown that the novel approach using FPGA technology for the implementation of signal switching matrices stands as the most desirable solution for this purpose.

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Keywords: Remote laboratory; Signal switching matrices; Comparison; FPGA

1. Introduction

With today's ever growing and expanding industry there is an ever increasing need for electrical engineers, as well as engineers in all other fields of industry. The teaching facilities, as universities, high schools, institutions for specialized trainings etc. are adapting to meet these needs/requirements by increasing the number of places available for this study area, sometimes neglecting the quality of the educational process. The part of the educational process that is most affected by this increasing number of students is the transfer of practical knowledge from the professor to students because of the lack of adequate laboratory spaces and equipment [1].

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Another point/aspect is computer integration - one of the main megatrends of modern technology. There are many outcomes from computer integration such as internet, computer aided technology, communications, mobile communications etc. Computer integration technologies have been disseminated and infiltrated into many engineering fields, giving us huge possibilities of acting at a distance. Therefore, computer integration program/technology motivates and runs the development of many remote learning platforms in all educational fields [2].

Therefore, one possible solution for this problem is the usage of remote laboratories. Remote laboratories are specialized laboratories which can be accessed by a network infrastructure, most commonly through Internet [3]. The basic idea behind this concept is to enable access to the laboratory equipment by using a personal computer with the effect that closely resembles to being physically present in the laboratory [4].

The existing remote laboratories mainly consist of the main microcontroller unit, in which the user code is downloaded, the peripherals with which the user remotely interacts through the mentioned microcontroller unit and the most important thing, the signal switching matrix module that is used for redirecting the user signals from any/all microcontroller pins to any/all peripherals pins.

Various switches can be used to enable this redirecting. Some existing solutions for the signal switching matrix module as well as the new approach to this problem will be presented and compared in this paper.

2. Existing solutions for signal switching matrices

2.1. Signal switching matrices in remote laboratory systems

In remote laboratory systems, signal switching matrices are used to enable the redirecting of user signals between the main microcontroller unit, which is the central part of a remote laboratory system, and its peripherals [5]. Different switching components can be used to redirect these signals. These components can be divided into two main groups, those that are controlled manually (e.g. toggle switches) and those that are software controlled (e.g. different types of relays, multiplexers/demultiplexers etc.).

The existing solutions regarding signal switching matrices, using both manually and software controlled switching components, with the assumption that forty inputs and forty outputs are needed, will be presented in the following text.

2.2. Toggle switch

The basic solution that arises for the realization of hardware interconnecting is the toggle switch. This is a manually controlled switch that has two states, on and off.

To enable the connection of any/all inputs to any/all outputs, one thousand and six hundred of these switches are needed. The implementation costs, as well as the amount of volume and surface needed when using toggle switches, are shown in Table 1.

Table 1. Characteristics of the toggle switch implementation.

	Unit	Amount
Quantity	pieces	1600
Total price	USD	1040
Total surface	cm^2	3500
Total volume	cm^3	11200

2.3. Mechanical relays

Signal switching matrices can also be implemented using relays. Relays are electrically operated switches. Considering their switching principles, there are two main types of relays, those that have moving parts for switching, and those that have no moving parts but they use semiconductor devices for switching instead.

In this case signal switching is implemented using mechanical relays. These relays have two overlapping iron nodes that are separated in non-operating conditions and only touch each other when the external voltage is applied.

One thousand and six hundred of these relays are needed to enable the interconnection of any/all inputs to any/all outputs. The implementation costs, as well as the amount of volume and surface needed when using reed relays, are shown in Table 2.

Table 2. Characteristics of the mechanical relay implementation.

	Unit	Pieces
Quantity	pieces	1600
Total price	USD	2225
Total surface	cm^2	5568
Total volume	cm^3	8185

2.4. Solid state relays

Solid state relays, compared to mechanical relays, have no moving parts. Instead, they use semiconductor devices for switching.

Like both toggle switches and mechanical relays, one thousand and six-hundred solid state relays are needed to implement a signal switching of any/all inputs to any/all outputs. The implementation costs, as well as the amount of volume and surface needed when using solid state relays, are shown in Table 3.

Table 3. Characteristics of the solid state relay implementation.

	Unit	Pieces
Quantity	pieces	1600
Total price	USD	6320
Total surface	cm^2	5557
Total volume	cm^3	13892

2.5. Digital multiplexer and demultiplexer switches

Digital multiplexers and demultiplexers offer another solution for the implementation of signal switching matrix module. These devices allow the data flow in one direction only and the signal switching matrix module must have the bidirectional property. That is why both multiplexer and demultiplexer components have to be used in this implementation.

Multiplexers provide the possibility to connect one of multiple inputs to one output, and the demultiplexer provides the possibility to connect one of multiple outputs that in this case serve as inputs, to one of the inputs, that in this case serve as outputs. In this way the bidirectional property of signal switching is achieved. The results for this category are shown in table 4.

Table 4. Characteristics of digital multiplexer and demultiplexer implementation.

	Unit	Pieces
Quantity	pieces	240 + 240
Total price	USD	360
Total surface	cm^2	1302

2.6. Analog multiplexer/demultiplexer switches

Another existing solution for the implementation of signal switching matrix is the analog multiplexer/demultiplexer component. This component has bidirectional pins so it can work as a multiplexer, allowing the user to address one of multiple inputs to one output, or as a demultiplexer, allowing the user to address an input to one of multiple outputs. There are various sizes of these components considering the number of inputs/outputs.

To allow the signal switching of any/all inputs to any/all outputs, two hundred and forty “8 to 1” multiplexer/demultiplexer components are used. The implementation costs, as well as the amount of surface needed when using multiplexer/demultiplexer, are shown in Table 5.

Table 5. Characteristics of analog multiplexer and demultiplexer implementation.

	Unit	Pieces
Quantity	pieces	240
Total price	USD	343
Total surface	cm^2	262

2.7. Crosspoint switches

The last of the existing solutions for the implementation of the signal switching matrix shown in this paper is the crosspoint switch.

This is a type of switch that can connect multiple inputs to multiple outputs in a matrix manner, using an assembly of individual switches between these inputs and outputs. This switch has the bidirectional property, so it allows the flow of data in both directions.

Like multiplexer/demultiplexer components, there are various sizes of these switches considering the number of inputs/outputs. For the purpose of this solution, twenty five “8 to 8” crosspoint switches are used to allow the signal switching of any/all inputs to any/all outputs. The implementation costs, as well as the amount of surface needed when using crosspoint switches, are shown in Table 6.

Table 6. Characteristics of crosspoint implementation.

	Unit	Pieces
Quantity	pieces	25
Total price	USD	236
Total surface	cm^2	25

3. A novel aproach using FPGA technology

3.1. Implementation method

A field-programmable gate array (FPGA) is an integrated circuit designed to be configured by a customer or a designer after manufacturing and that is why it is called field-programmable. FPGAs contain programmable logic components called “logic blocks”, and a hierarchy of reconfigurable interconnections that allow the blocks to be “wired together”, somewhat like many changeable logic gates that can be wired together into many different configurations. That enables the user to set up their own hardware structure inside a single FPGA device. With this property it is possible to implement a signal switching matrix inside a single FPGA device.

The schematic of the implementation is shown in Figure 1. The simplest way to describe the implementation method is to start from switches that are lowest in the implementation hierarchy. In Figure 1, their names are “Switch 1” to “Switch 40”. These are bidirectional switches, implemented by using three tristate buffers. Two of these buffers are used to determine the direction of data flow, which is done by setting the correct “Switch control” pin, shown in Figure 1, to the appropriate state. The third buffer is used to enable the data flow, thus controlling which switch is active at the given moment. This buffer is controlled by the appropriate "Switch enable" pin. Each of these switches has one data input pin separated from other switches, and one output pin that is common to all switches. Forty of these switches form one "40-to-1" switch that can also be seen in Figure 1. This switch has forty inputs and one output and, since forty outputs are needed, forty "40-to-1" switches are used. Inputs of all these switches are connected to a common bus that is connected to user input pins. Outputs of these switches are connected separately to user output pins as shown in Figure 1. Each one of these switches has an address input pin that allows the user to control which switch is active at a given time. In this way the user can choose which one of the input pins is connected to which output pin and vice versa.

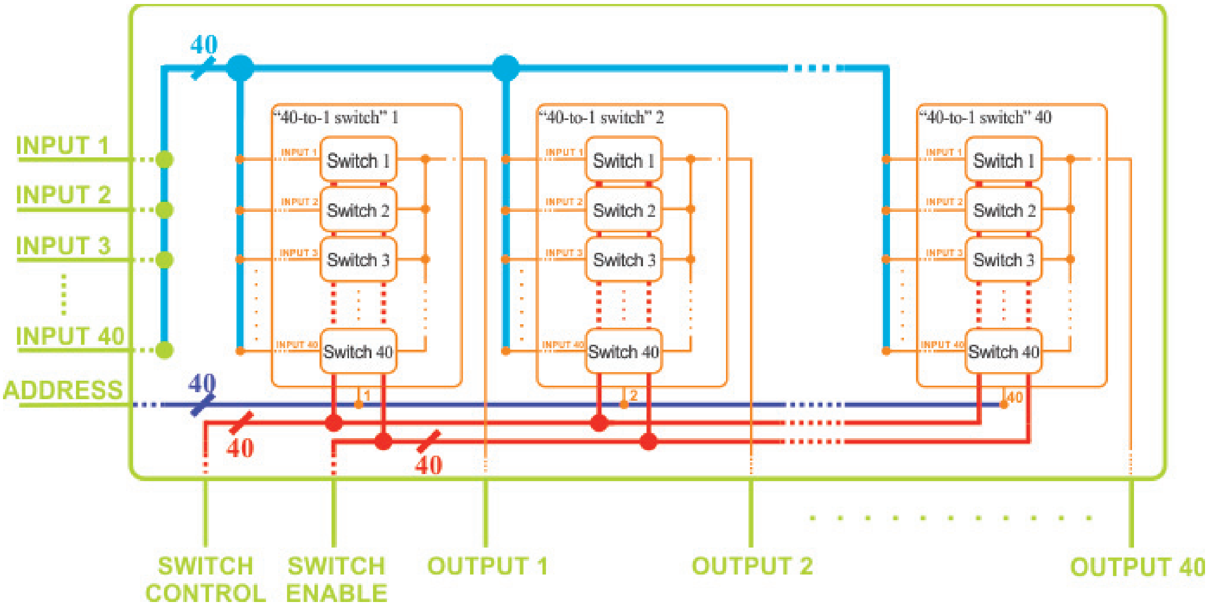

Fig. 1. Implementation of the signal switching matrix using an FPGA device.

3.2. Implementation results

By the above mentioned method signal switching of forty to forty pins was successfully implemented inside a single FPGA device. It is worth mentioning that, although input and output pins are bidirectional, the user has to know the direction of data flow in advance and set the appropriate "Control" pin to allow the flow of data in the desired direction.

For the purpose of this implementation 70% of the given FPGAs capacity was used. Implementation costs, as well as the amount of surface needed when using this FPGA for the implementation of the signal switching matrix are shown in Table 7.

Table 7. Characteristics of FPGA implementation.

	Unit	Pieces
Quantity	pieces	1
Total price	USD	164
Total surface	cm^2	16

4. Comparison of signal switching matrix solutions and a new solution using FPGA technology

The first of the proposed existing solutions for the signal switching matrix, the toggle switch, is a solution that has the advantage in the simplicity of implementation and its bidirectional property so the user doesn't have to know the direction of data flow in advance. One other advantage of this solution is the possibility to interconnect both digital and analog signals. Beside these advantages, this implementation solution has quite a few disadvantages. One thousand and six hundred of these switches are needed for the implementation purposes which result in a large surface requirement, as shown in Figure 2(b). When implementation price is considered, these switches have an advantage over the solutions using relays, as it can be seen in Figure 2(a), but still the expenses are considerably higher as compared to digital mux and demux, analog mux/demux, crosspoint and FPGA solutions. The biggest disadvantage of this solution is the lack of the software control possibility and the signal switching can only be done manually, so this implementation is not suitable for the remote laboratory signal switching purposes.

Reed and solid state relays are the two other existing solutions that were proposed. Like toggle switch, both of these solutions have the bidirectional property so the user doesn't have to know the data flow direction in advance and they too have the ability to interconnect both digital and analog signals. Relays have a big advantage over toggle switches as they can be software controlled. Implementation costs and surface requirements are two big disadvantages of both of these solutions. In both solutions, one thousand and six hundred relays are needed, which results in considerably higher implementation costs than other solutions, as shown in Figure 2(a). As compared to other solutions, surface requirements for both relay implementations are much higher, as shown in Figure 2(b).

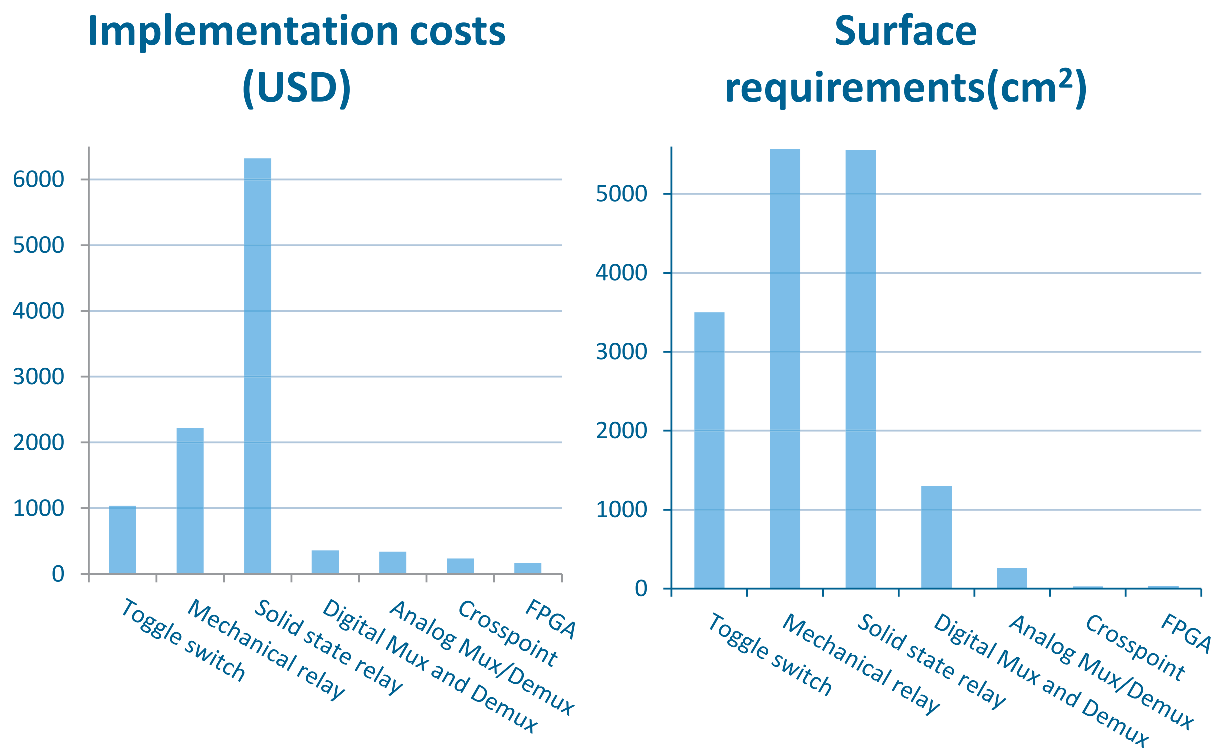

Fig. 2. (a). Implementation costs of various solutions regarding the signal switching matrices;

(b) Surface requirements for various implementation solution regarding the signal switching matrices.

Another proposed solution, using digital multiplexer and demultiplexer devices, has an advantage when implementation costs are considered, as shown in Figure 2(a). Like relay solutions, it can also be software controlled but the user has to know in advance whether to use multiplexers or demultiplexers depending on the direction of data flow, and it has only digital inputs and outputs.

This solution requires fewer components than the toggle switch and relay solutions, but still has a considerably larger surface requirement than the analog mux/demux, crosspoint and FPGA solutions, as seen in Figure 2(b).

The solution which uses analog mux/demux components is very similar to the previous solution, when it comes to implementation costs shown in Figure 2(a), but it requires two times less components and is bidirectional so the user doesn't have to know the direction of data flow in advance. When the surface requirement is considered, this solution has a much smaller surface requirement that the already compared existing solutions, but that is still considerably higher as compared to the crosspoint and FPGA solutions.

The crosspoint solution has the lowest implementation costs and surface requirements of all solutions except the FPGA solution, and this can be seen respectably in Figure 2(a) and Figure 2(b). The advantage over the FPGA solution is the bidirectional property of this switch, but on the other side, it can only interconnect analog signals.

As mentioned, the FPGA device has the lowest implementation costs and surface requirements of all the proposed solutions and requires far less components than all other solutions, in fact only one FPGA device is needed to implement the signal switching matrix. The only disadvantage of the FPGA solution is that it can interconnect only digital signals, so the user has to know the direction of data flow in advance.

5. Conclusion

Nowadays, the world requires an increasing number of electrical engineers, especially in the field of automation and embedded systems. High schools and universities tend to adapt to that need by increasing the number of places available for study in these areas. This increasing number of places forces lecturers and students to be focused on a single technical subject without sufficient cross-disciplinary integration of knowledge and experience [6]. This produces students who generally have very poor ability to integrate both theoretical knowledge and practical experience into two or more subjects and to apply them to real life engineering problems [7, 8].

One possible solution for the postulated problem is the Remote laboratory. As mentioned, the existing remote laboratories mainly consist of the main microcontroller unit, the peripherals with which the user remotely interacts through the mentioned microcontroller unit and the most important thing, the signal switching matrix module that is used for redirecting the user signals from any/all microcontroller pins to any/all peripherals pins.

The main idea behind this article was the comparison of existing solutions (toggle switches, mechanical and solid state relays, digital multiplexer and demultiplexer switches, analog multiplexer/demultiplexer switches, crosspoint switches) for the signal switching matrix module as well as the proposal for a new approach using an FPGA device.

The results of the comparison show that the implementation of the signal switching matrix using an FPGA device has an insensibly smaller surface than the crosspoint switch solution, but significantly smaller than all the other solutions, as seen in Figure 2(b). When it comes to implementation costs, the FPGA solution costs are lower than all the other implementation solutions. The only limitation of this solution is that it can interconnect only digital signals and the user has to know the direction of data flow in advance. This presents a problem when using peripherals that have various pins with different data flow directions. This limitation, however, has been easily solved, as described in Section 3.1. Considering the given facts, a novel approach using FPGA technology regarding the implementation of signal switching matrix stands out as the most desirable solution for this purpose.

The partial implementation of the remote laboratory has shown positive results and the concept of the signal switching matrix using an FPGA device has proved to be efficient and most desirable solution in the terms of implementation costs and surface requirements.

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