# A MICROPROCESSOR BASED MULTICHANNEL ELECTRICAL STIMULATOR FOR HUMAN EXTREMITIES

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## ABSTRACT

In order to evaluate the effects of a multichannel electrical stimulation for human extremities is extremely important to be able to change and modify very easily the stimulation parameters.

This goal is obtained controlling the electrical stimulator with a microprocessor system. The main advantages of this approach are:

- the laboratory version of the stimulator can be made extremely versatile. Pulse frequency, duration and amplitude can be controlled both predefining a precise strategy both using some close loop signals to change, on line, the previously defined parameters.
- the final version will be a portable general purpose multichannel stimulator, that, on the other hand, can be tailored to have the most appropriate stimulation strategy to came closer to the patient needs.

The main characteristics of the prototype are:

- up to six channel can be driven in the actual version, but, due to the modularity of the system, there are no limits to the channel number.
- pulse frequency and duration can be software modified during the stimulation time; these parameters are common to the six channels.
- pulse amplitude can be indipendently regulated on each channel by a factor of 256.

The system is built around an 8 bit microprocessor system, using the "MUBUS" standard, developed at the "Istituto di Elettronica e Telecomunicazioni" of the Politecnico of Turin. This solution allows an high degree of modularity.

In this paper the achievable features of a microprocessor multichannel stimulator are shown, a prototype version of the laboratory system is described and preliminary results are presented.

## INTRODUCTION

The use of FES (Functional Electrical Stimulation) for rehabilitation purposes can be divided into two basic steps:

A) The evaluation of the subject's deficiencies. This step, once completely left to the physician's experience, can now be assisted by automatic measurement systems, generally minicomputer based, that can furnish both a more complete information and the automatic link to an adaptive controller of stimulation parameters;

B) The choice of the stimulation patterns for mono or pluri-channel stimulators to match the patient requirements.

These two steps are cohordinated by skilled personnel , physicians, therapists who close the loop between evaluation and the pattern choice.

The rising use of microprocessors providing low cost, low power and low size powerful computing and automatic control performances, can help to close more efficiently this loop.

Portable data acquisition and computing systems could substitute minicomputer based ones and handle adaptatively, at the same time, the stimulation task.

The microcomputer based programmable stimulator presented here is an approach to this problem and has been conceived more as a laboratory research instrument to investigated the system possibilities and advantages than as a complete, self-standing apparatus for immediate and extensive use.

Flexibility and generality, easy interfacing with different peripherals ( e.g. analog and digital data acquisition systems) are the main characteristics of the design, based on the MUBUS standard microprocessor bus used in our laboratory.

## 1 - SYSTEM DESCRIPTION

An example of a block diagram of a closed loop system allowing to provide a stimulation pattern, to evaluate its effects, and to optimize its parameters to obtain the desired goal is shown in fig.1.

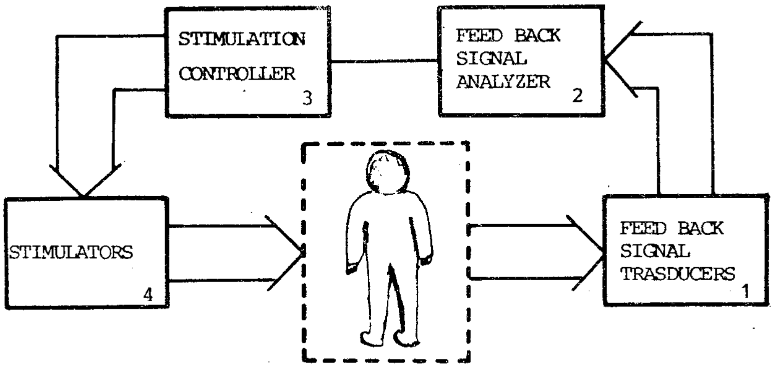

Fig. 1 - BLOCK DIAGRAM OF A CLOSED LOOP STIMULATION SYSTEM

Block 1 performs the acquisition of the feedback signals and sends the measured values to the functional unit 2 which process them extracting the significant parameters and decides the modifications to the stimulation pattern. Block 3 analyzes the changes and controls the stimulators (block 4 ).

The various elements of the complete system can be implemented in different ways. The closed loop could be completely automatic with a built-in modification strategy for the stimulation patterns; on the other hand the evaluation of the stimulation results and the consequent strategy of change can be accomplished by an operator; some facilities can be provided to the operator to ease this task.

This paper describes in detail the characteristics of an apparatus performing the functions of blocks 2 and 3.

The main requirements of a control for a multichannel stimulator are:

- The capability of controlling a set of channels with a large modularity.
- The possibility of a complete control of the parameters of the stimulation waveform, such as:
  1) the amplitude of the stimulation pulses, chosen independently on each channel.
  2) the frequency ($f = \frac{1}{T}$) and width ( $\tau$ ) of the stimulation pulses.
- The capability of modifying on line the stimulation pattern according to feedback parameters, or to provide off-line facilities to an operator.

The previous requirements make necessary the use of an intelligent stimulation controller based on a microcomputer, mainly in view of a portable version.

To implement the microcomputer part of the stimulator we exploited the facilities offered by the modular microprocessor development system based on MUBUS standard (1). This structure allows to implement microcomputer based machines at different levels of complexity starting from basic modules.

The block diagram of the system is shown in fig.2 . It is possible to observe that due to the bus oriented organization other modules can be added if necessary.

Obviously the general purpose elements (CPU, RAM, ROM) have not been designed expressely for this application. The design efforts have been devoted to the blocks performing D/A convertion and to the controlled pulse generator.

A first version of the program for the generation of stimulation pattern has also been produced. A special attention has been paid to obtain expandable and modular software.

The main hardware and software characteristics are described in the following two paragraphs.

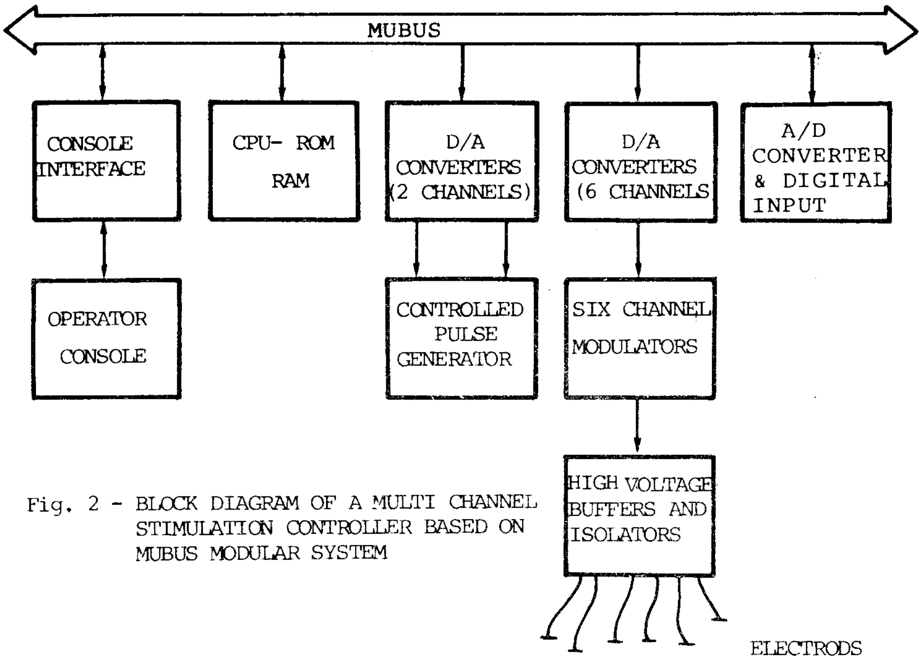

Fig. 2 - BLOCK DIAGRAM OF A MULTI CHANNEL STIMULATION CONTROLLER BASED ON MUBUS MODULAR SYSTEM

## 2 - Hardware organization

The block diagram of the circuitry for the stimulator control is shown in fig.3. The output of the module is the stimulation waveform, a typical example is presented in fig. 4. The structure allowing to obtain the previous waveform is indicated in fig. 5, it basically consists of an electronic switch sampling the input waveform provided by the D/A converter. The output voltage is so a train of pulses which duration and repetition rate is that of the control signal. Pulse amplitude is the current voltage value . The control signal is obtained from a voltage oscillator implemented by an integrated function generator (INTERSIL 8038). Frequency and pulse duration are independently controlled by analog voltages provided by two D/A converters(8 bit). The actual version allows to support up to six indipendent stimulation channels,this number seems to be sufficient in all kind of application (2).

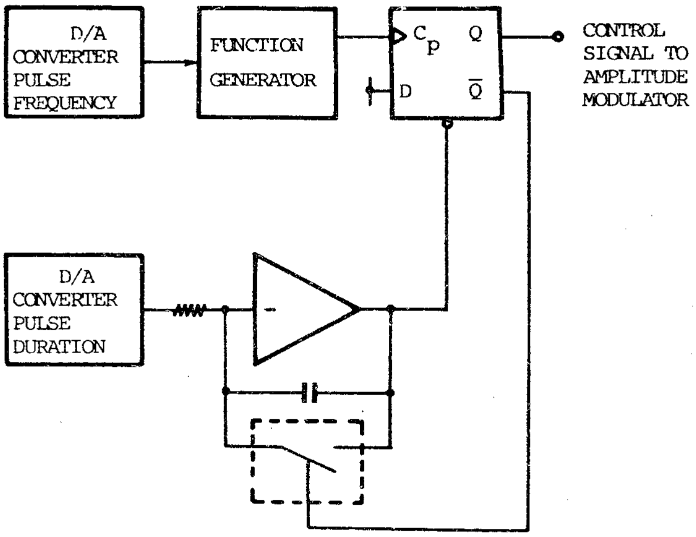

Fig. 3 - BLOCK DIAGRAM OF THE STIMULATOR CONTROL

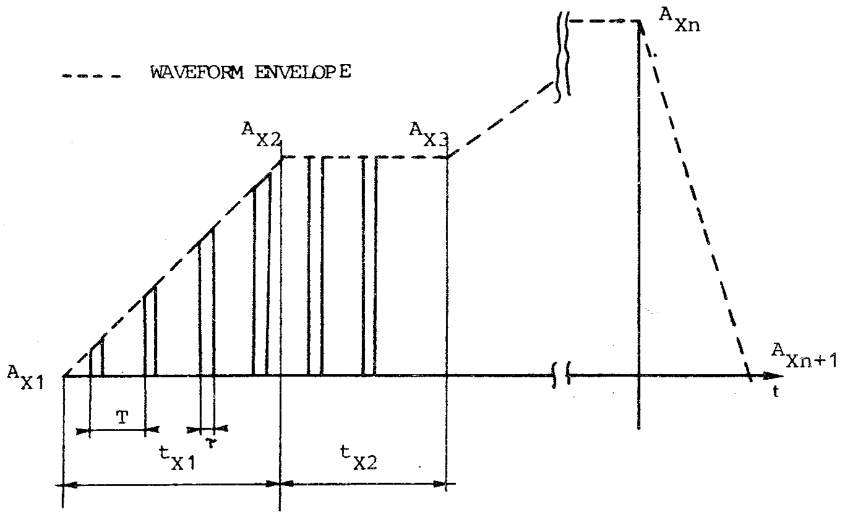

Fig. 4 - STIMULATION WAVEFORM (WITH NO AC COUPLING) FOR CHANNEL X

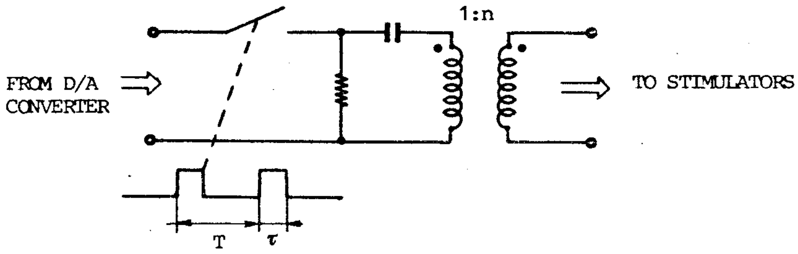

Fig. 5 - BASIC SCHEME FOR THE AMPLITUDE MODULATION

The scheme of one of the six channels is indicated in fig.6. It is possible to obtain output pulse trains with the following electrical characteristics:

$V_{DC} = 0$ V $V_{pp} = 0 \div 100$ V $\quad I_{pp} = 0 \div 5$ mA

$f = 1/T = 10 \div 100$ Hz $\quad \tau = 0.05 \div 2$ ms.

The input block allowing to receive analog and/or digital feedback signals from the patient are standard input modules without specific characteristics.

The system is intendend to be used with external stimulator whose design is very simple and its functions are AC coupling and buffering.

## 3 - Software structure

The developed software allows now to perform periodical stimulation syncronized by a feedback signal. The operator can define a piecewise envelope of the stimulation for each channel by means of an interactive program using an operator console. Frequency and pulse duration, common to the all channels, are defined in the same way. The stimulation parameters are stored in the computer memory and can be punched on a paper tape, to be used afterwards.

The envelope is defined for a channel X by the following parameters:

| | | |
|---|---|---|
| CHANNEL X | $A_{X1}$ | $t_{X1}$ |
| | $A_{X2}$ | $t_{X2}$ |
| | ........... | |
| | $A_{Xy}$ | $t_{Xy}$ |
| | ........... | |
| | $A_{Xn}$ | $t_{Xn}$ |
| | $A_{Xn+1}$ | |

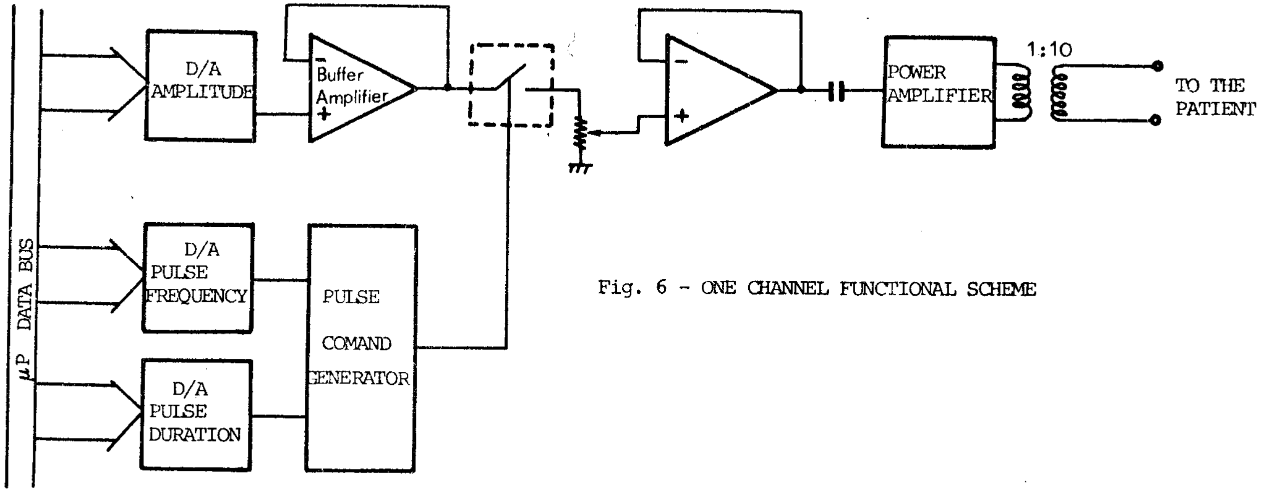

Fig. 6 - ONE CHANNEL FUNCTIONAL SCHEME

An internal real time clock forces the system, every millisecond to change the stimulation amplitude according to the preaviouly defined pattern. In order to obtain a linear variation between two defined points, there must be every millisecond an increment:

$$\Delta_{Xy} = \frac{A_{Xy+1} - A_{Xy}}{t_{Xy}}$$

with $t_{Xy}$ expressed in milliseconds. All $\Delta_{Xy}$ are calculated by the microcomputer before the beginning of the stimulation. The parameters introduced by the operator and those evaluated are placed in a table (fig. 7a) which is resident in memory.

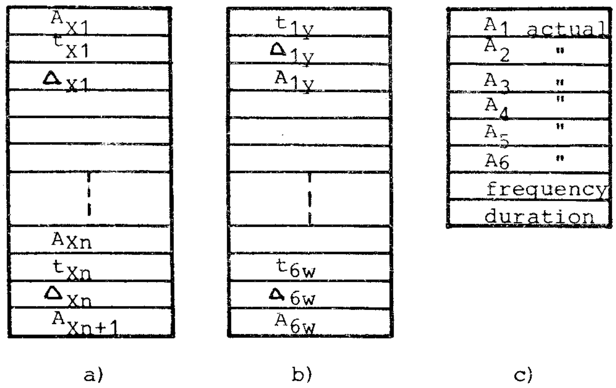

Fig. 7 - a) TABLE DEFINING STIMULATION PATTERN FOR 1 CHANNEL

b) TABLE CARRYNG ALL THE INFORMATION NECESSARY TO UPDATE TABLE c)

c) CURRENT VALUE OF STIMULATION PARAMETERS

Using N channels, every stimulation pattern requires N tables. When the tables are set up, the system is ready to begin operations; first frequency and pulse duration are fixed then the control waits for an external syncronizing signal, when it arrives a stimulation cycle begins. At the end of this first cycle the control stops and waits again for a new syncronizing pulse, and so on. During the stimulation two other tables are used. The first one contains, for every channel:

- the current slope ($\Delta_{Xy}$) of the stimulation pattern,
- a counter $t_X$ which is decremented every millisecond, that, when at zero, flags slope changes,
- the final value $A_{Xy}$ of the current piece of envelope which is used as a starting point for the next piece, to avoid amplitude errors due to sum iteration.

This table, with the exception of $t_X$ is updated only every time the envelope of one channel change slope. Update operation consists of a transfer from table a) to table b) of the parameters concerning the next piece of the envelope ($A_{xy}$ , $t_x$, $\Delta_{xy}$) . A second table contains the informations to be sent to the output every millisecond. These value are updated every millisecond by adding the proper $\Delta$ . The use of the intermediate table b) allows to reduce updating time for table c) .

This activity, for a periodically repeated stimulation, does'nt use all CPU time (only a 25%), so it is possible to insert parallel task to handle feedback signals in order to properly modify the stimulation pattern.

A possible solution will be to modify the stimulation parameters of the next cycle during the previous one.

## CONCLUSIONS

The system described, modular both in hardware and software can be efficiently used for the study of multichannel stimulation and closed loop control with easy programming of stimulation patterns and interface to measurement systems. Further expansions could be the connection to a goniometric gait evaluation system and to a multichannel mioelectric signal data acquisition system.

The actual laboratory prototype will be mainly used to better investigate the limits and the possibilities of this kind of approach in view of the use of a multimicroprocessor system.

## REFERENCES

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(2) A.Trnkoczy,U.Stanic,M.Malezic,R.Acimovic,N.Gros: The development of multichannel FES stimulators for gait correction in paretic patients. 1^ Mediterranean Conf. on M.B.E. Sorrento Sept. 1977.