

MICROCONTROLLER-BASED ECG SIMULATOR PROTOTYPE

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The paper presents a prototype of ECG simulator, which may be a beneficial tool in designing and debugging of automatic diagnosis software methods implemented in real ECG devices. The main advantages of the proposed simulator are both the expanded memory capacity and the easy approach for reconfiguration of the memory content, data format and sampling frequency.

1. INTRODUCTION

Nowadays, the automatic analysis of the electrocardiogram (ECG) has become an advisable tool in the long-term monitoring ECG devices like holters for cardiac arrhythmia and for ventricular fibrillation detection. The built-in algorithm for automatic ECG interpretation must match the accuracy of specialists. The general society of software developers usually applies the commonly accepted databases [1,2,3] during initial development and testing of the PC based algorithms for automatic diagnosis. However, the testing and validation of these software methods implemented in real ECG devices demand of precise long-term ECG simulators.

The aim of the present work was to develop a portable one-channel ECG simulator prototype, needed for testing of automatic defibrillators. It should be able to generate analog signals of hours duration and to reproduce the amplitude and frequency accuracy of the standardised training databases. By including normal sinus rhythms, different arrhythmia types and test waveforms, the proposed device becomes also suitable both for medical equipment maintenance and educational purposes.

2. SIMULATOR PROTOTYPE DEVELOPMENT

2.1 Technical specifications of the ECG simulator prototype

- Output amplitude range:
 - low voltage output (-5mV ÷ 5mV);
 - high voltage output (0V ÷ 4V);
- 2 MB data flash memory;
- 8 functional buttons for selection of one of the available eight configurable forms. They represent memory segments with a re-programmable length (up to 2MB) and start address. ECG data with the following characteristics can be stored:

- 8, 10 and 12 bit format of the sampled data;
- 100,125,200,250,400,500,800 and 1000 Hz sampling frequencies;
- 2 functional buttons for selection of one of the available two forms for test signals with fixed start address, 8 bits data format, 250 Hz sampling frequency;
- 2 functional buttons for fast forward and backward rewinding of the generated ECG signal (4 times faster);
- Pace button - pacing pulse with 0.5V amplitude, 1ms pulse duration and 800ms period;
- 2 control buttons – On/Off and Play/Stop;
- 14 LED indicators;
- Electrically isolated PC connection by RS232, providing the possibility for reading, writing and configuration of the forms by using an in-house developed software for personal computer (PC);
- Power supply – three rechargeable accumulators type AA (1.2V). Internal battery charging by connection to charge adapter;
- Size – 14 x 7.5 x 3 cm;
- Weight – 185 g (without batteries).

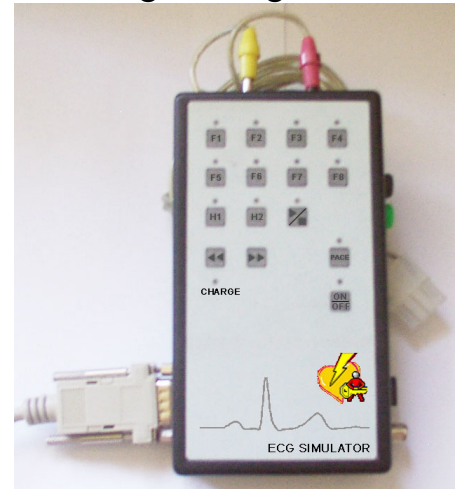


Fig.1. General view of the ECG simulator

2.2 Hardware concept

The block circuit of the main hardware components of the ECG simulator prototype is shown in figure 2. It is based on the PIC18F452 Microchip's microcontroller because of its low power consumption and extended built-in periphery. The operation frequency of 3.6864 MHz is synchronized with the RS232 interface PC standards. The built-in 1536 B RAM and 32 kB FLASH ensure the operation and the program memory resource requirements. By means of SPI communication, the data memory is expanded up to 2 MB using four external FLASH memory chips of 512 kB (AT45DB041 - Atmel). The capacity of this memory is enough to store 12 bits ECG signals with sampling frequency of 250 Hz and more than one hour duration. The SPI is used also to control the digital-to-analog ECG data conversion, which is realized with 12-bit D/A converter (AD5320 - Analog Devices). The one-channel D/A converter voltage output is buffered and is passed through a differential attenuator, thus providing ± 5 mV amplitude range of the output ECG signal. A pace maker pulse with 0.5 V amplitude, 1 ms pulse duration and 800 ms period may be independently generated with controlled high-energy capacitor C1(100uF) discharge through the relatively high resistance R5 (500 Ω). The pace pulse is then superimposed on the output ECG signal. The choice and control of the simulator operation mode is provided by 15 button keyboard and 14 LED indication, both realized with matrix selection through 4 rows and 4 columns. RS-232 interface (MAX232 - Maxim) and optocouplers (PC714 - Toshiba) provide an optical isolated connection with PC during the configuration mode of the ECG simulator. The connection is guaranteed with bit rate of 57600.

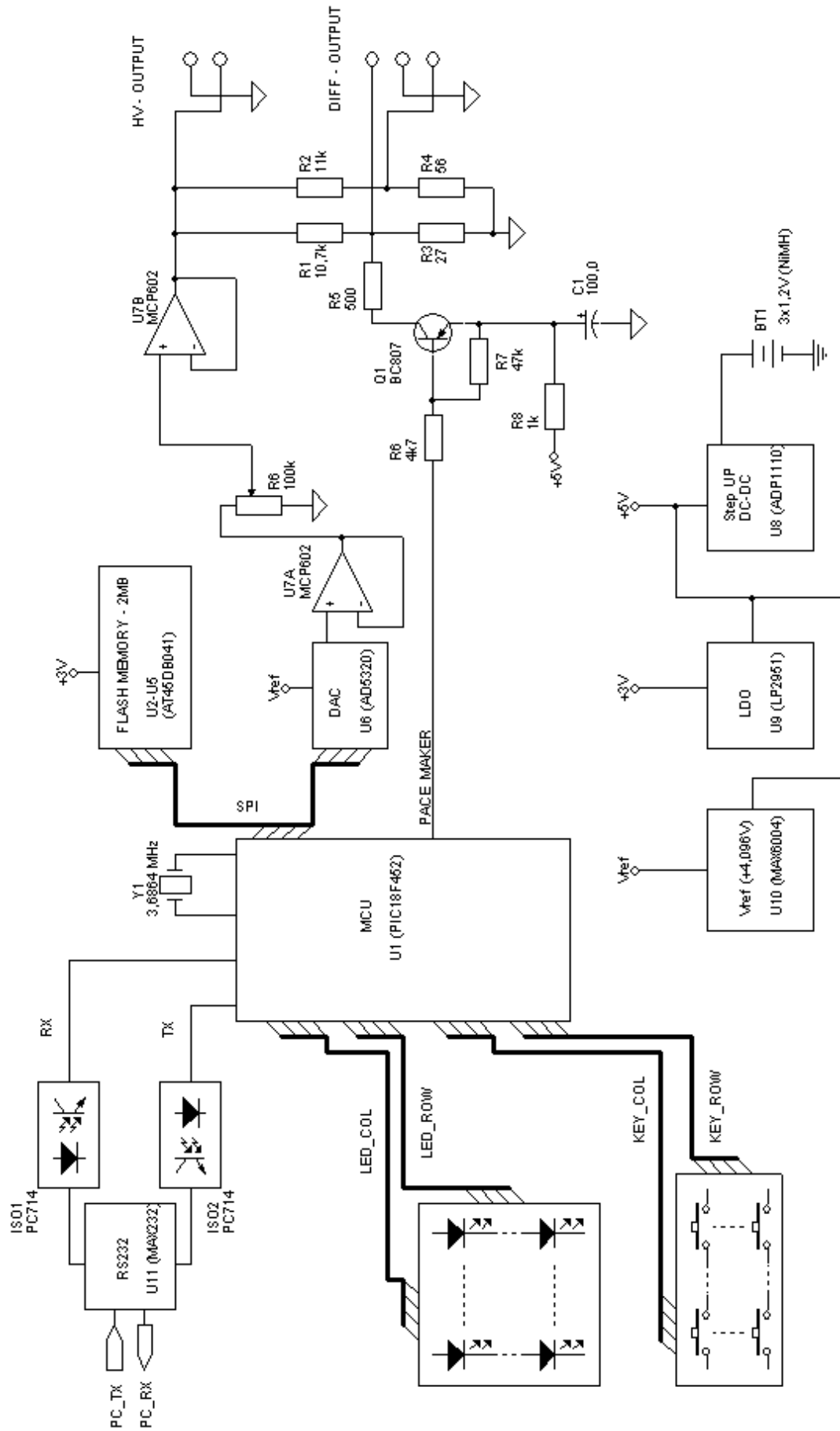


Fig.2. Block circuit of the ECG simulator prototype

The power supply is provided by three parallel accumulators (1.2 V). A 'Step-Up' DC-DC converter (ADP1110 - Analog Devices) assures the supply voltage (5 V) for the entire circuit. Since the flash memory operates with 3V supply voltage, a 'Low Drop' regulator (LP2951 - National Semiconductors) reduces its voltage from 5 V to 3V. The DAC reference voltage (4.096 V) is generated by MAX6004 (Maxim).

2.3 Software concept

The software placed in the internal MCU FLASH is developed in C language. Its flow chart is illustrated in figure 3. A special feature is the possibility to select between fixed forms (8-bit test signals stored in 1 kB internal MCU FLASH) and configurable forms (from 8 to 12-bit ECG recordings, placed in 2 MB external FLASH memory).

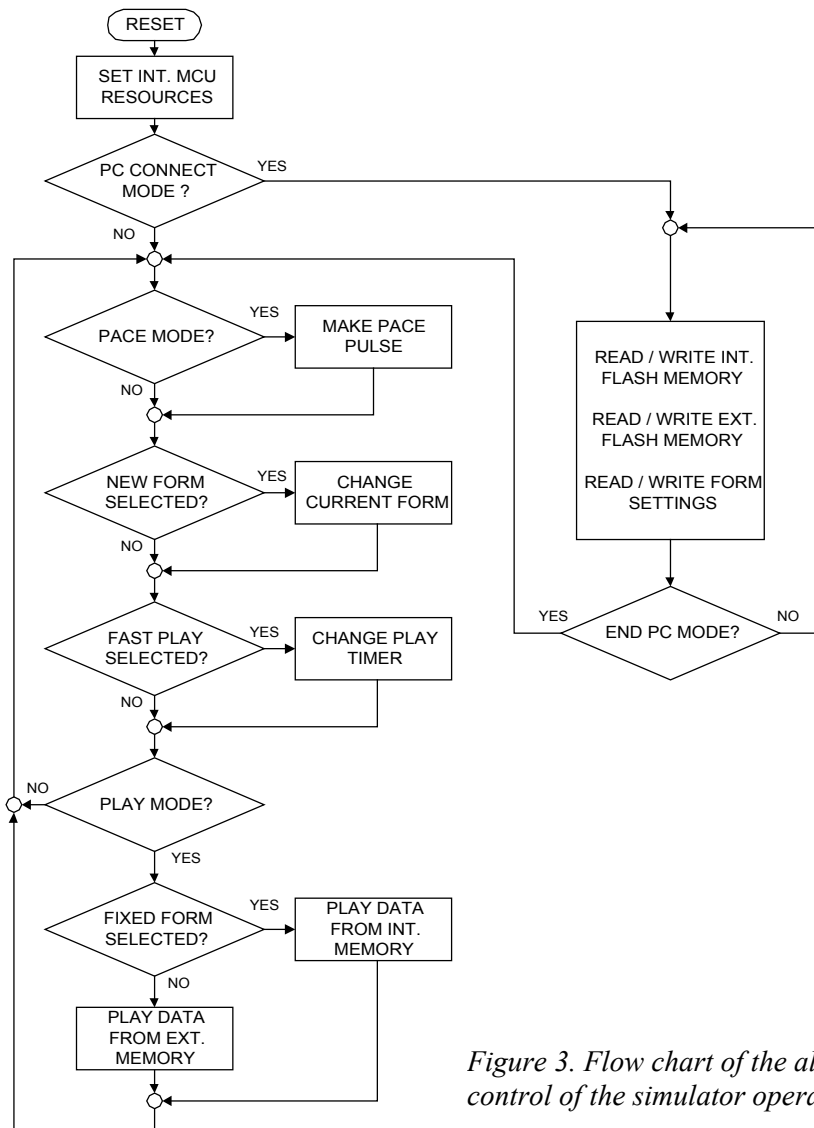
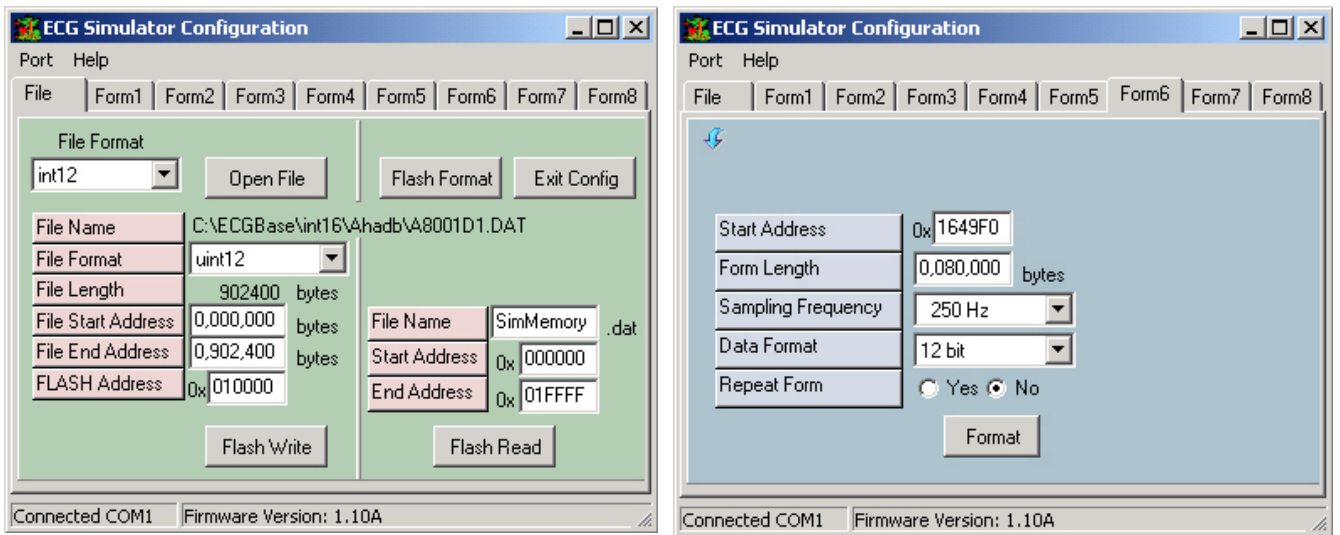


Figure 3. Flow chart of the algorithm for control of the simulator operation.

3. ECG SIMULATOR CONFIGURATION WITH PC

In-house developed PC software running under any Windows platform is used for simulator configuration (see figure 4). It enables opening of ECG recordings with different data formats (int/uint 8,10,12,16) and downloading part of them at a specified start flash address (0x000000 - 0x1FFFFFF). The size of the downloaded



(a) (b)
 Figure 4. General View of the PC software utility for ECG simulator configuration.
 (a) – Window for downloading, uploading and formatting of the simulator memory;
 (b) - Window for setting the data format in a configurable Form.

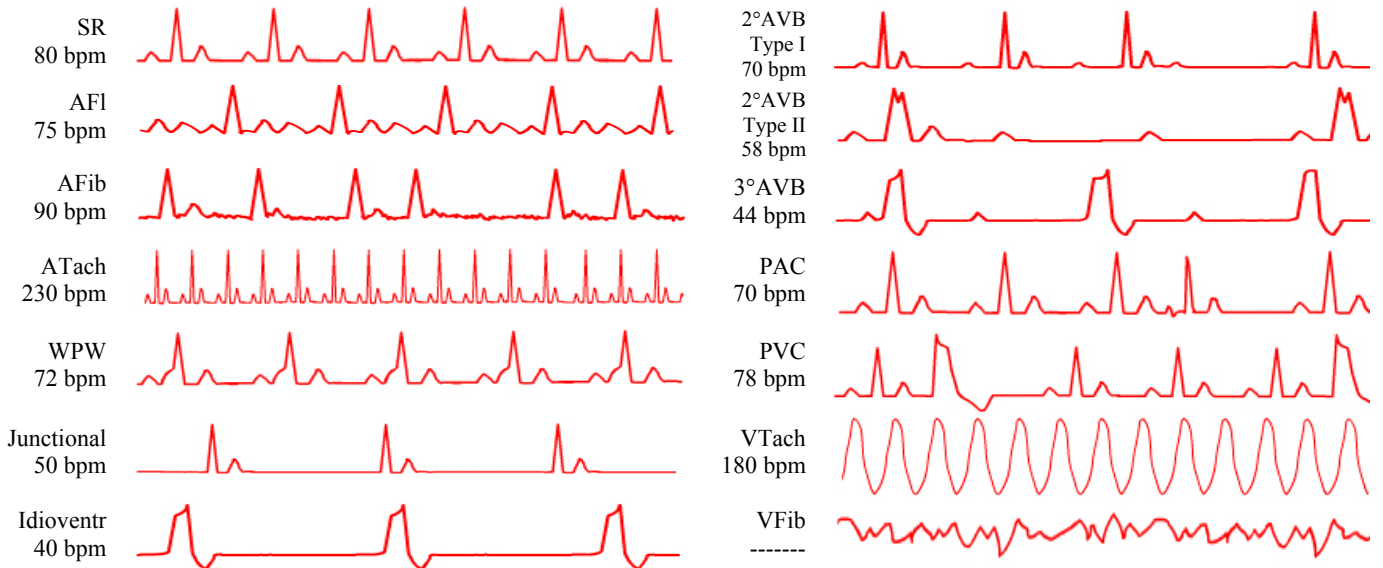


Figure 5. Examples of 4s synthesized ECG test forms of different arrhythmia types.

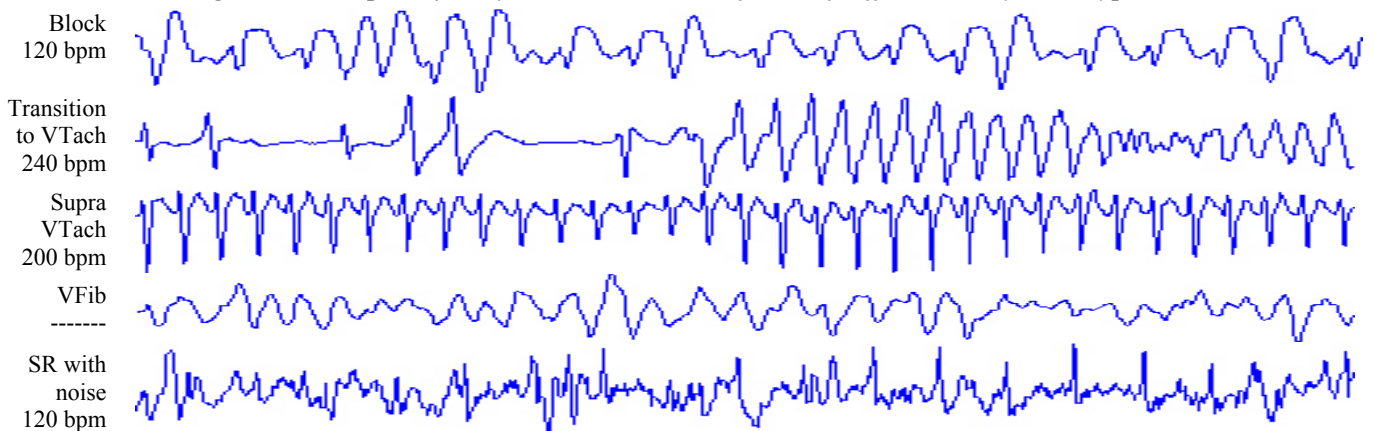


Figure 6. Examples of 10s segments of real ECG recordings with different heart function disturbances.

data is defined by selecting the file start/end address and by specifying a new data format (uint 8,10,12). The software gives the possibility to upload the flash memory content into a PC file and also to clear the entire flash memory. Each of the 8 configurable forms can be programmed (start address: 0x000000 - 0x1FFFFFF; form length: up to 2 MB; sampling frequency 100, 125, 200, 250, 400, 500, 800 and 1000 Hz; data format: uint 8,10,12; enable/disable of infinite closed loop signals).

4. ECG SIGNALS AND VERIFICATION

We synthesized a set of ECG signals, which cover the most common real life rhythms of normal morphology and arrhythmia types. Several examples of 4s ECG patterns are shown in figure 5 as follows: sinus rhythm (SR); atrial flutter (AFI), fibrillation (AFib) and tachycardia (ATach); Wolff-Parkinson-White syndrome (WPW); junctional and idioventricular rhythm; atrio-ventricular blocks (AVB); premature atrial (PAC) and ventricular (PVC) contractions; ventricular tachycardia (VTach) and fibrillation (VFib). Figure 6 illustrates examples of 10s ECG segments, extracted from long-duration ECG databases [1,2,3], acquired in real recording conditions.

The functionality and the waveform generation capabilities of the ECG simulator prototype were verified by testing several types of automatic external defibrillators produced by Schiller Company (FRED easy, easyport). Tests were also done by in-house developed ventricular fibrillation detection module with PC connection, which provides the possibility for displaying the generated ECG signal on the PC screen.

5. DISCUSSION AND CONCLUSION

Compared to a previous work [4], the main advantage of the presented simulator is the expanded memory capacity, which allows the storage of more than 4^{1/2} hours of 8-bit ECG recordings with sampling frequency of 125 Hz. When the ECG simulator is used for testing, it can reproduce exactly the real recording conditions of long-term training ECG databases, like fast transition between sinus rhythm, ectopic beats, tachycardia and fibrillation; amplitude and frequency signal modulation; pace pulses; noise from bad electrode contact, electrode or patient movement, tremor and cardio-pulmonary resuscitation artifacts etc. Another advantage is the easy approach for simulator memory reconfiguration, which makes the simulator an important recourse for medicine teaching, allowing the visualization of some signals that rarely appear in clinical routine. The general application of the presented ECG and arrhythmia simulator is for medical equipment maintenance and for development and testing of automatic diagnosis software methods implemented in real ECG devices.

6. REFERENCES

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