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Simplesmart Inc.
School of Engineering Science
Burnaby, BC V5A 1S6
crouching-monkey@sfu.ca

November 5, 2001

Dr. Andrew Rawicz
School of Engineering Science
Burnaby, British Columbia
V5A 1S6

Re: Design Specifications for the Pace Maker Beat Recognition System

Dear Dr. Rawicz:

The attached document, *Design Specifications for the Pace Maker Beat Recognition System*, outlines the design of our project for ENSC 340. The goal of this project is to design an effective, user-friendly real-time tempo detection device that will aid musicians in developing their rhythmic skills and in maintaining their desired tempo in live performance.

This document describes in detail the design of our Pace Maker system, and its various sub-components. Our project is an ambitious venture – combining exciting algorithm development, DSP coding, and hardware design.

This document will act as a guide to help us coordinate our efforts to complete this project. Should you have any questions or concerns regarding our proposal, please feel free to contact me by phone: (604) 727-9454 or via email: crouching-monkey@sfu.ca.

Sincerely,

Dan Toews
CEO
Simplesmart Inc.

Enclosure: Design Specifications for The *Pace Maker Beat Recognition System*

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Design Specifications for the Pace Maker Beat Recognition System

Submitted by: Dan Toews
Grzegorz M. Misa
Yasaman Mohammadi
Prashan Gunasingam

Submitted to: Dr. Andrew Rawicz (ENSC 340)
School of Engineering Science
Simon Fraser University

Steve Whitmore (ENSC 305)
School of Engineering Science
Simon Fraser University

Date: October 15, 2001
Version: 1.3

Contact Person: Dan Toews, *CEO*
Simplesmart Inc.
E-mail: dtoews@sfu.ca

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Abstract

> *The goal of any aspiring musician is complete freedom - to throw away all bounds on creativity. Yet, musicians face the task of creating music that can be listened to and understood by others. If no measures are taken to constrain the music within certain bounds of* rhythm *and* pitch*, a song can easily become unintelligible. Perfection in music is approached through a healthy balance of creative freedom and discernable form.*

One of the two vitally important fundamental elements of music is rhythm. Studies have shown that people respond to and recall the rhythms of their favorite songs as much as they do the melodies and lyrics. Although rhythm is a skill that requires much effort and practice, little effort has gone into building tools to help students and professionals develop their rhythmic abilities.

Simplesmart stands poised to unleash one of the world's first tools designed to provide real-time feedback to musicians on their rhythm. The Pace Maker is a beat recognition device, which will provide a musician with information on the tempo at which he/she is playing. Although other devices exist to help musicians keep a steady rhythm (such as the metronome), Pace Maker will be the first device to unobtrusively aid a musician's rhythm without imposing a rigid form which must be followed.

Further to our Project Proposal and Functional Specifications, this document details the design of the Pace Maker system and its sub-components. Design issues specific to our proof-of-concept design (to be demonstrated in December 2001) and our final production design (to be released in the Fall of 2002) are considered in depth.

The development and design of our embedded beat-recognition software is enclosed, as well as an extensive collection of test procedures for the developing algorithms and the final production units.

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1. Introduction

The Pace Maker is a real-time musical beat tracking system designed for use by drummers and percussionists. By processing a musical performance in real-time with our embedded beat-recognition software, Pace Maker determines the current tempo of the music and provides this information to the musician in a useful and unobtrusive manner.

The Pace Maker will benefit drummers and percussionists by aiding them in the training of their rhythmic skills and intuition, and by presenting them with a level of control over the music they produce that has been previously unavailable.

Our embedded beat-recognition software is combined with a practical, effective set of features and a straightforward user interface - making the Pace Maker a valuable (in fact nearly indispensable) addition to any musician's setup.

1.1. Glossary of Terms

- **BPM** (beats-per-minute): a measure of the tempo, or pace, of music. Represents the number of pulse notes that can be played successively in one minute (i.e. a pulse note that occurs at one second intervals relates to a BPM of 60). A.k.a. Maelzel's Metronome (MM) for Johann Nepomuk Maelzel (1772-1832), developer of the modern metronome.
- **DSP** (digital signal processing): a variety of microprocessors designed for performing intensive signal processing (for multimedia applications such as audio).
- **MIDI** (musical instrument digital interface): a set of hardware ports (IN, OUT, THRU) and software standards that allow devices to communicate musical performance information (i.e. note / tempo information etc.).
- **MIDI Clock**: a digital clock standard which communicates tempo (i.e. indicates the occurance of pulse notes).
- **Piezo**: an element which converts mechanical vibration into an electrical signal.
- **Pulse Note**: the main dividing beat in rhythmic music.
- **Trigger**: the trigger included with the Pace Maker system is a piezo transducer-equipped drum trigger (commonly used as an input to an electronic drum module). The trigger acts as an input button, which is mounted on the drum kit and struck with a drumstick. The Pace Maker determines a tempo from the trigger by counting the time between successive hits.

1.2. System Overview

The Pace Maker beat detection system includes the following components:

- Main unit including the processing hardware, tempo display and i/o connectors
- Cymbal stand clamp and rack-mount hardware for the main unit
- Trigger with hi-hat/cymbal stand clamp
- Power adapter and trigger cable

In addition to the included components, a user will require a microphone/microphones, a simple mixer and, of course, a drum set or other percussion instruments. It's also possible to use the Pace Maker system with electronic percussion. In this situation, the microphone and mixer are not required - the user simply plugs the line-out of the electronic sound module into Pace Maker's line-input. See Figure 1 for a high-level overview of the complete Pace Maker system.

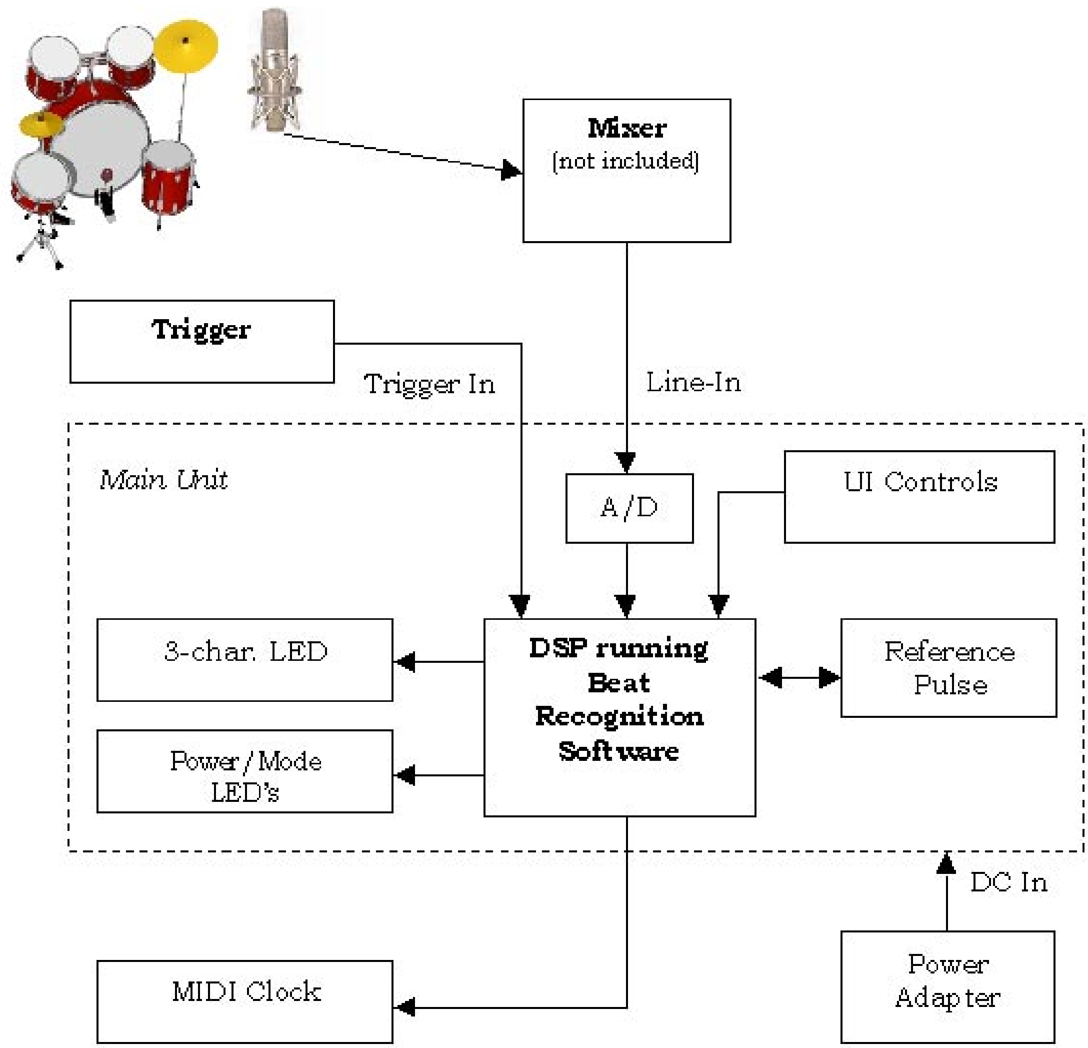

Figure 1: Pace Maker System High-Level Overview

1.3. System Operation

The Pace Maker is intended for use by drummers and percussionists of all skill levels, in a variety of situations. The system is equally suited for live performance, studio sessions, rehearsing, home practice and education.

1.3.1. I/O

The system has two input sources: the trigger (included) and the line-level audio input. The line-level audio input is intended to be fed by either a microphone / microphones (summed through a mixer) or a sound module (as used with an electronic drum kit).

The system has two separate outputs - the main output being a 3-character tempo display. The other output of the Pace Maker system is a MIDI clock, which transmits the tempo information as detected from the input sources.

The MIDI clock output makes it possible for a musician to control other sound sources (i.e. sequencers, samplers, etc.), from the Pace Maker's trigger or audio inputs. The possibilities are endless! A drummer is now able to add extra percussion sounds to a performance, or even control an entire sampled-symphony from behind a drum kit!

1.3.2. Modes of Operation

The unit has two separate modes of operation: *absolute* mode and *relative* mode.

1.3.2.1. Absolute Mode

In absolute mode, the unit simply detects and reports the tempo of the input audio source or the trigger (if played twice or more in succession). By using the trigger before starting a song, the performer can be sure that he/she is starting the song off in the proper tempo range.

1.3.2.2. Relative Mode

Relative mode allows a performer to set a reference pulse to which any further playing is compared. The difference between the reference pulse and the currently detected tempo is then displayed to the performer so that he/she may adjust the playing accordingly.

In relative mode, if the trigger is played twice or more in succession (and then left for one second[1]), the reference pulse is set to the tempo defined by the last two trigger hits. Alternatively, by striking the trigger once (and waiting for one second) while in the middle of playing, the system sets the reference pulse to the currently detected tempo from the input audio source. Thus, the performer is able to reset the reference pulse in the middle of a song by simply striking the trigger once.

1.3.3. Tempo Limits / Resolution

The Pace Maker system is able to detect tempos between the range of 60-240 BPM. This range is representative of a vast majority of musical samples. The cost of providing a broader range of tempo detection is prohibitive to the design – requiring more processing power.

Despite this limitation, the system is still very useable when playing outside of the tempo range. The unit will still detect an appropriate pulse - only it will be a multiple of the actual tempo (i.e. if playing at 300 BPM the unit will recognize this as half-time, or 150 BPM). This will provide the user with appropriate feedback and can still control other sources via MIDI, keeping them in time with the performance.

[1] Two trigger strikes which occur over one second apart do not fall within the system's lower beat-detection limit of 60 BPM.

1.3.4. Mounting Options

The Pace Maker system includes two mounting options. The first and most widely used option is to mount the main unit to a cymbal stand (or similar secure structure, via the included clamp) in close proximity to the performer. However, the unit is also supplied with rack-mount brackets, so that the unit may be mounted in a half-rack space (standard half-rack size is approx. 213mm wide, 44.3mm high).

A standard hi-hat / cymbal mount is included so the trigger may be mounted on a drum kit or in a percussion setup.

2. User Interface Design

The Pace Maker system is a versatile tool, used largely in performing situations, where flawless, predictable operation and ease-of-use is essential. For this reason, much effort has been put into making the system's design extremely musician friendly.

The main processing unit has a perfectly simple interface, as shown in Figure 2. The front panel consists of two buttons and a display. On either side of the 3-character display are the power and mode buttons, each of which has an LED in the center to indicate the power and mode status respectively.

The rear panel consists of the trigger and audio line-level inputs, DC input jack, and MIDI output jack.

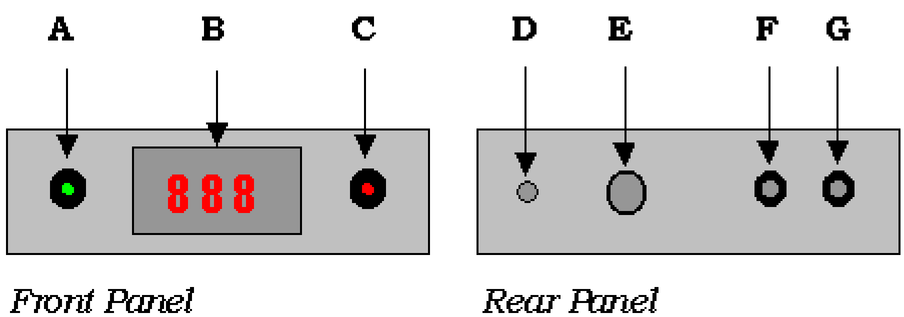

Figure 2: Main Unit UI Overview

A. Mode button and LED
B. 3-character tempo display
C. Power button and power on LED
D. DC power adapter input
E. MIDI output
F. Trigger Input
G. Audio line-level input

Special consideration was given to every aspect of the unit's design. The power and mode buttons are both located on the front of the unit for easy access and are recessed in order to avoid accidental pressing or being struck by an errant drumstick. The LED's in the center of the buttons provide the musician with a quick status check at-a-glance.

The tempo display consists of three large (20mm tall) 7-segment LED's, which provide a bright, easy-to-read display to the musician, even on the darkest of stages. The sparse front-panel controls and relatively few lights mean that the performer will be able to get the information he/she needs from the device easily, and without distraction.

Once the mode of operation has been set to fit the musician's needs, the only remaining function (setting the reference pulse if in relative mode) is controlled by the trigger. The performer is able to reset the reference pulse to the current tempo quickly and easily with one tap on the trigger.

3. External Hardware

3.1. Main Processing Unit

The Pace Maker system (with the exception of the trigger input and power supply) is housed in a rugged rack / drum mountable unit. Table 1 below gives a condensed overview of the required properties of the main unit.

Dimensions:

Width:	213mm
Height:	44.3mm
Depth:	~80-120mm (dependant on the final PCB)

Electrical Properties:

Operating Power:	5VDC, <1000mA

Mechanical Properties:

Mean Time Between Failure:	Exceeding 1,000 hours
Duty Cycle (jacks and buttons):	>10,000 cycles

Environmental Properties:

Operating Temperature Range:	-20 °C to 45 °C
Durability:	Must withstand moderate vibrations and potential drum-stick abuse

Table 1: Physical Hardware Properties[2]

The dimensions of the unit are chosen to fit in a standard half-rack unit or be mounted (with the included clamp) to a cymbal stand or other piece of hardware.

3.1.1. Main Unit Materials

The materials chosen for the main processing unit reflect the environment in which the unit is used.

Body:	Stainless steel (type 410, annealed)
Display cover:	Plexiglas
Rack-mount brackets;	Stainless steel (type 410, annealed)
Internal shock-absorption:	Latex foam rubber

Table 2: Main Unit Materials

Shown above in Table 2, are the materials used in the construction of the Pace Maker's main unit. A rugged, 3.2 mm thick, type 410 stainless steel is used for the body of the unit due to its easy availability and strength. The unit is designed to withstand repeated abuse from errant drumsticks[2]. The front panel of the unit has an extra Plexiglas cover over the 3-character tempo display to protect the LED's from being struck.

[2] Please see Section: 6. Testing

The PCB inside of the main unit is attached to the box via four rubber connectors. Latex foam rubber is also used to hold the PCB steady, while absorbing much of the shock which is translated to the main unit through the cymbal stand clamp or through being struck accidentally by a drumstick.

3.1.2. Front Panel

The two front panel buttons (power and mode) are recessed to avoid being struck accidentally by a drumstick. The buttons have LED's in their centers to indicate power on status and mode of operation.

There are three 7 segment LEDs which provide tempo feedback to the end user. Figure 3displays the physical dimensions and structure of the LTS-3401L series LED while Figure 4 displays their pin layout.

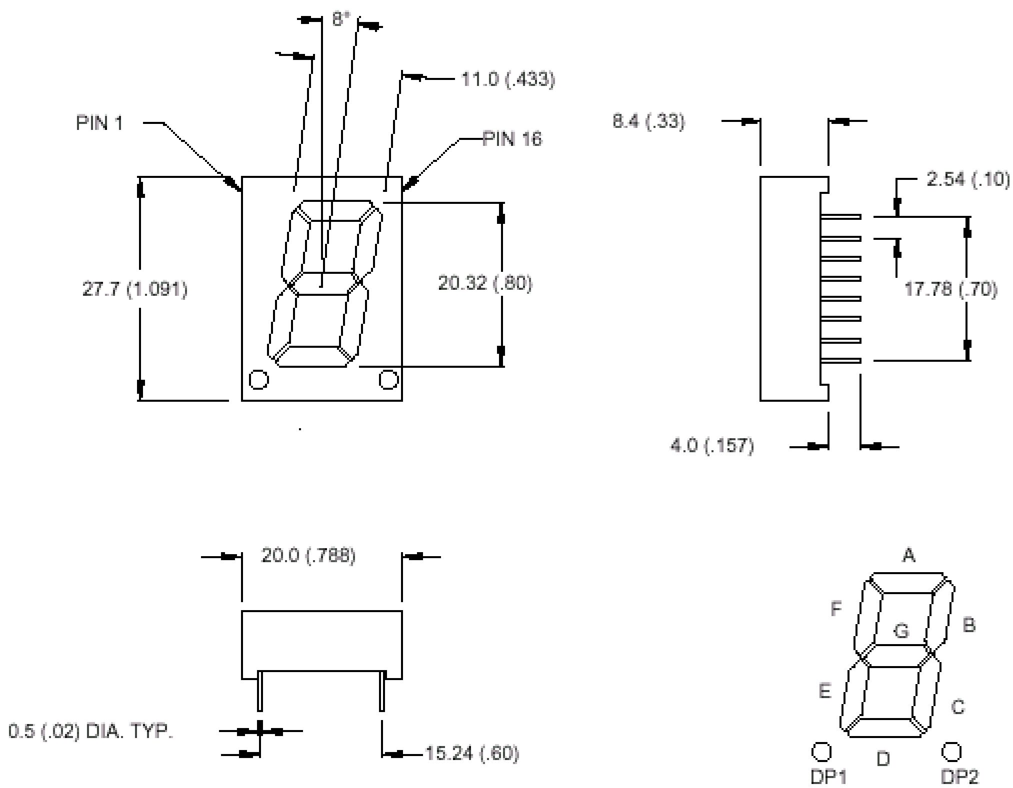

Figure 3: Seven-segment LED

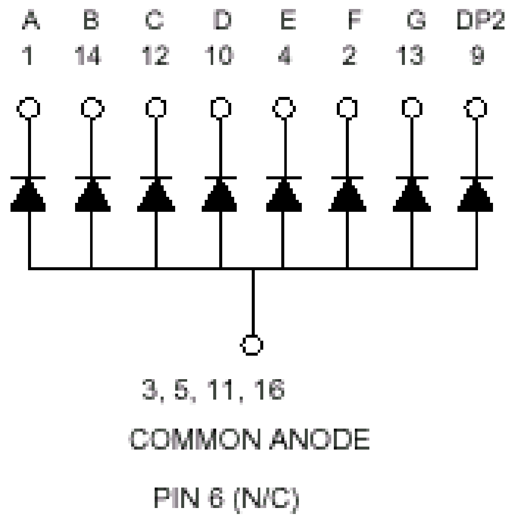

Figure 4: Pin layout for LED

The LTS-3401L series LED's are inexpensive, large and bright – providing adequate feedback under any lighting conditions. The tempo display is recessed in the front panel and covered with a piece of Plexiglas to protect the LED's.

3.1.3. Rear Panel

As shown in Figure 2, the rear panel houses the line-level audio and trigger input jacks, the MIDI clock output jack and the power transformer input. Neutrik connectors are used for the audio, trigger and MIDI jacks. These connectors are high-quality units, with copper-alloy contacts, excellent electrical characteristics (contact resistance <6mΩ) and a mechanical life of greater than 10,000 cycles. They Comply with IEC 68-2-20 standards for solderability and have an operating temperature range of (-20°C to 65°C).

3.2. Power Supply

The operating power listed in Table 1 was chosen to fit the requirements of the electronic hardware and the output of standard power transformers. A wall-plug class-2 transformer (operating on 120V, 60Hz), purchased from a vendor such as Condor, is included with the product. These power transformers are CSA approved, UL listed and require no testing.

The power transformer is supplied with a long (~6m) cable for reaching far-away power outlets from on-stage.

3.3. Trigger

The trigger supplied with the Pace Maker system is a tube-shaped single electronic trigger, similar to the one shown in Figure 5. The trigger body is made from steel, while the strikeable surface is a latex foam rubber. Underneath the latex foam is a piezo transducer, which translates the mechanical vibration from the foam into an electrical potential. A 3m cable is supplied to connect the trigger to the main unit, as the trigger will be mounted on the drum kit near to the main unit.

Figure 5: Trigger

4. Electronic Hardware

The Pace Maker proof-of-concept design is scheduled for demonstration in December 2001. This design is being implemented on a Texas Instruments PCI development board (installed in a personal computer). This platform is extremely flexible and versatile, lending itself well to system development and rapid prototyping. The Pace Maker production units will use a code-compatible TI DSP chip on a custom PCB (printed circuit board). This section contains information on the production design hardware as well as our proof-of-concept development platform.

4.1. Production Design

4.1.1. DSP Board

Figure 6 below shows a block diagram of our production design PCB.

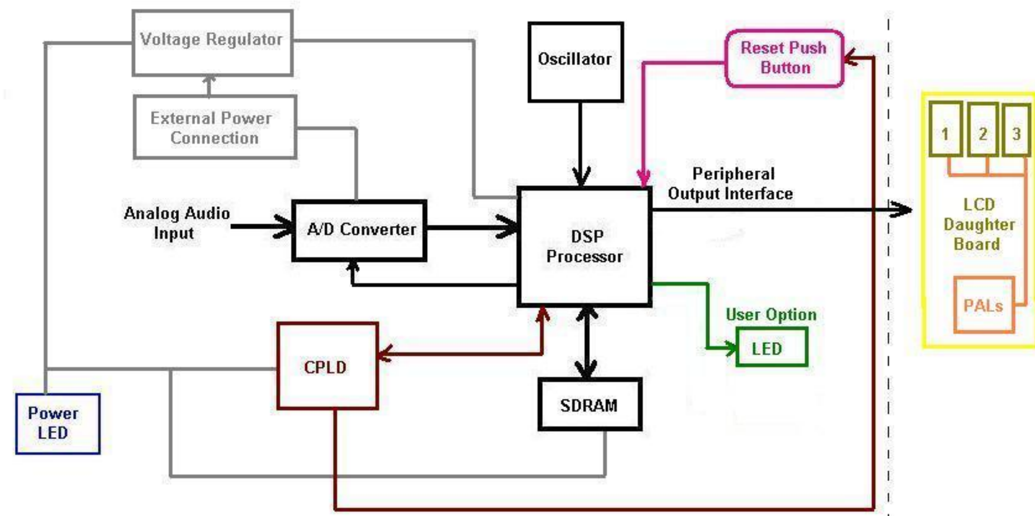

Figure 6: PCB Architecture of Production Unit

The following is the list of components required for the production unit PCB:

- DSP chip: Texas Instruments TMS320C24x family chip, with 16-bit fixed point DSP and Flash (boot loader)
- CPLD: programmable logic provides the board's glue-logic and control/status registers
- User/power LEDs: indicators on the board. One is used whenever the board is powered up properly and the other LED is used for mode status (absolute/relative)
- Reset pushbutton: manual reset control on the board providing board reset signal, and software reset control signals.
- Voltage regulator: to provide 1.8 V or 2.5 V for the DSP core; 3.3 V for the DSP I/O, memories, CPLD, and buffers
- External power connector: of 5 V used for all digital components which are not powered up by the voltage regulator.
- SDRAM: external memory of at least 2Mb
- Oscillators: providing the clock source for the DSP

- *Peripheral output interface*: enable the use of a custom daughterboard providing use of the DSP internal peripherals. For this product, the output interface is a 6-bit digital output to the daughterboard hosting the tempo display LED's
- *Audio interface*: 16-bit input audio interface with line-level input

The Texas Instruments TMS320C24x DSP processor is used on the Pace Maker production units. This device was chosen because it is code-compatible with our TI development platform (see Section 4.2) and is the lowest cost TI DSP device which suits our application.

The DSP is used to program several banks of comb filters, as well as four 4th-order IIR filters. The analog audio signal is digitized using the 10-bit analog to digital converter. As we use 512 sample frames for tempo calculations, we need at least 512 x 16 bits = 8Kb of memory which is provided using the expansion memory interface. For more accurate A/D resolution, an external 16-bit A/D IC is added to the board. The A/D conversion is operated at a sampling frequency of approx. 22050Hz, which gives us the required frequencies for performing our frequency separation and beat-detection algorithms (see Section 5). Table 3 shows the TMS320C24x's relevant specifications.

MIPS	40	Measure of computing performance (our algorithm only requires low MIPS)
Frequency (MHz)	40	Clock rate at which the DSP operates
RAM (Words)	2.5K	Internal memory
Boot Loader Available	ROM	Needed for stand alone operation
Development Tools	YES	Texas Instruments (TI) ANSI C Compiler, Assembler/Linker, and Code Composer Studio™ Debugger; Evaluation Modules
External Memory Interface	YES	Needed to expand the memory outside the chip on the board.
10-bit A/D (#Channels)	16	16 channels of 10-bit Analog to Digital Converters
Conversion Time (us)	500ns	Corresponding to number of MIPS.
Timers	4	Used to control the processing of Data and timing of output
Other: Low cost, easy development, portable from TI evaluation board.		

Table 3: TMS320C24x DSP Specifications

4.1.2. Tempo Display

In the Proof-of-Concept Design (see Section 4.2) the Altera MAX EMP7128S 7000 is used to interface the DSP with the three character tempo display. For the production design however, there is no need for an FPGA, since they are much to dense and expensive for the purpose of our application. Instead, a simple programmable logic device (PLD), such as a programmable array logic (PAL) IC is quite sufficient. Therefore, for the production design three TIBPAL 16L8-15C PALs are used. The structure and pin layout for each of these PALs is displayed in Figure 7.

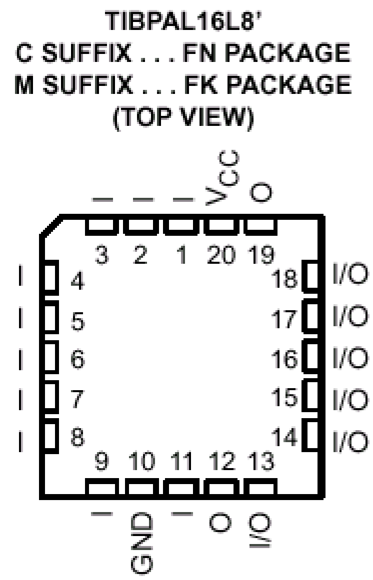

Figure 7 PAL pin layout

Three PALs are used instead of one because of the scarcity and price of a single PAL with the required number of pins. The number of pins required is 24 output pins (8 per each LED) and 6 input pins. Therefore, three of the chosen PALs satisfy this requirement. The block diagram for this setup is displayed in Figure 8 below.

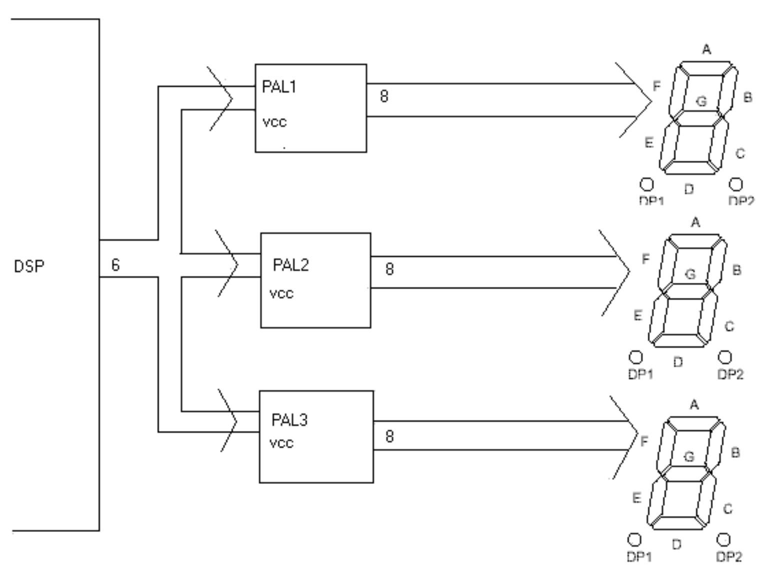

Figure 8: LED Interface on Display Daughter Board

Based on the first two bits of the 6-bit input code, the appropriate LED will be updated to the value of the last four bits.

4.2. Proof-of-Concept Design

Our proof-of-concept design platform consists of an advanced DSP embedded system in the form of an evaluation module with all the necessary components (including external input/output interfaces) mounted on the board. The proof-of-concept design has, in addition to this board, the user interface controls (mode switch, trigger/audio inputs) and the 3-character tempo display.

4.2.1. TI Evaluation Board

For the development of the Pace Maker beat-recognition system, we have utilized the Texas Instruments TMS320C6x Evaluation Board. This is a PCI board which installs directly into any personal computer. This evaluation board was chosen because of its flexibility, power and interface capabilities with Matlab and Simulink (are chosen development platform). Information on this board can be found in Appendix A.

4.2.2. Tempo Display

An Altera UP 1 CPLD Board is used to interface the PCB board with the three external 7-segment LED's. The specific FPGA, embedded on the UP 1 board is the MAX EMP7128S 7000 device.

Each LED is connected to and controlled by the output pins on the MAX 7000 FPGA. In order to turn a segment of the LED on, a low is applied to the FPGA's output pin connected to that specific segment. The common connection of all display segments is connected to a + 5V supply. Supplying this high voltage is common practice and leads to brighter LED's since TTL outputs traditionally provide more current at the low level.

The 3 LED's will be capable of representing a 3 digit number, from 000 to 999. The decimals on the LED's will not be used since the output will not produce decimal values. A 6-bit binary value will be the input to the FPGA board produced by the PCB. Logic is required to convert from this 6-bit binary value to the 3-character display and is accomplished with a decoder.

5. Firmware

5.1. Signal Flow

Our embedded beat-recognition software operates on 10-bit (or 16-bit) audio data sampled at a rate of approximately 22050Hz. The algorithm first separates the input audio into a number of separate frequency bands using 4th order IIR filters. This is done in order to isolate particular elements of the percussive audio input. Each frequency band is then accumulated into frames of 512 samples and averaged (this averaging is essentially a form of down sampling the signal).

The averaged frequency bands are then fed into the beat candidate detection algorithm. The outputs of these blocks then feed the final heuristic tempo detection routine, which chooses the most likely tempo estimate and outputs it to the 3-character display and MIDI clock. Figure 9 below gives an overview of the whole system.

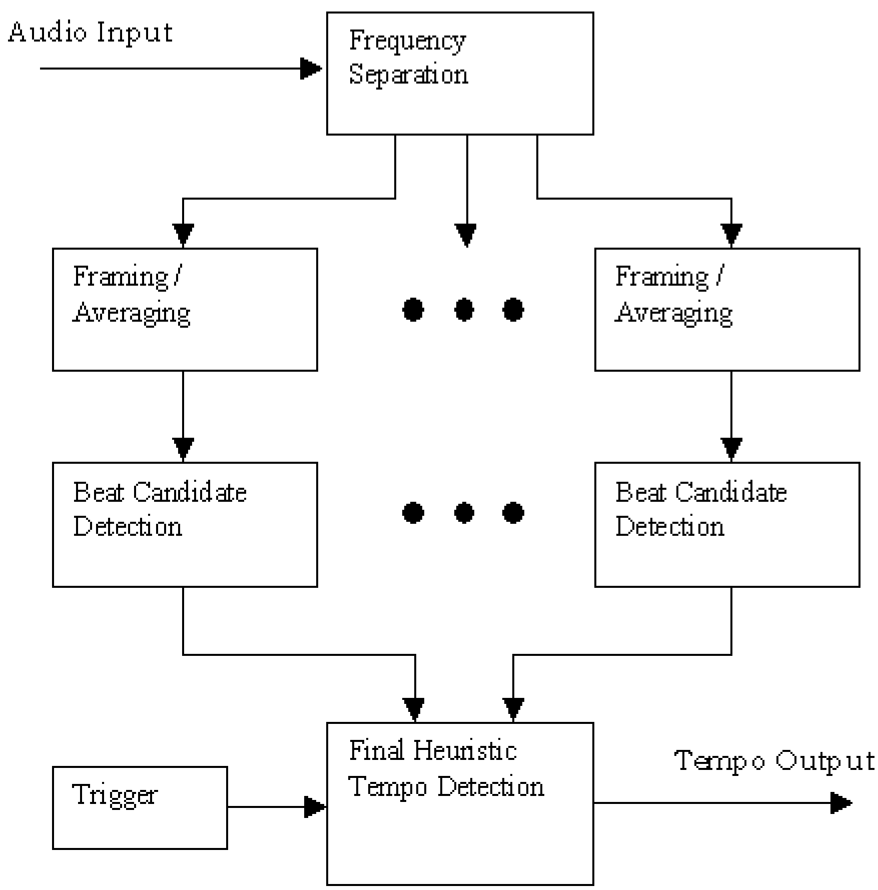

Figure 9: Beat Detection Algorithm Overview

5.2. Beat Detection

The beat candidate detection blocks operate on the principle of resonant comb filterbanks. By processing the averaged signal bands with a series of comb filters, each with a slightly varying length, the filter which corresponds to the tempo of the music will have a higher energy output than the other filters in the bank. What this means is that each separated frequency band of the input signal is processed by a series of comb filters, each of which corresponds to a particular tempo (BPM). The energies from these comb finterbanks are then fed into a block which performs a heuristic analysis of the tempo.

5.3. Heuristic Tempo Detection

As can be seen in Figure 9, the heuristic tempo detection block has two inputs: the energies from the beat candidate detection blocks and the trigger input. The trigger acts as a tap-tempo device, allowing the user to tune the heuristics to a particular tempo range. For example, if a user plays the trigger at an interval of 0.5 seconds (120 BPM), the heuristic tempo detection block will weight the beat candidates which fall in a range around 120 BPM more than the other candidates, making it more likely that a tempo of 120 BPM will be detected.

Pseudo Code for Heuristic Tempo Detection Block:

```
If trigger_input
    start trigger_counter
    wait for next trigger_input (time-out after 1 second)
        If 2nd trigger_input
            set tempo_bias around BPM defined by trigger_counter
            If operation_mode == 'relative'
                reference_pulse == BPM defined by trigger_counter
            else
                output_tempo = BPM defined by trigger_counter
        else        -- time-out
            if operation_mode == 'relative'
                reference_pulse == current_tempo
            else
                break
else                -- detect tempo from audio source
    multiply beat_candidates by tempo_bias
    possible_tempos == three most likely beat_candidates from each frequency band
    if mode(possible_tempos) exists
        current_tempo == mode(possible_tempos)
    else
        current_tempo == beat candidate with highest energy
    if operation_mode == 'relative'
        output_tempo == current_tempo – reference_pulse
    else
        output_tempo == current_tempo
end
```

This pseudo code demonstrates how the Pace Maker system works in conjunction with an audio input source and a trigger input source to detect the tempo of either input and reset the reference pulse when in relative mode.

6. Testing

This section outlines the tests that are performed to ensure that the Pace Maker device meets the required level of quality and durability.

6.1. Physical Tests

Test	Description
1. Drop Test	The device is dropped from a height of 2m onto a hard surface (polished cement), simulating the device being knocked off a flat surface or hitting the ground as a result of the stand being tipped over. This test is performed 10 times and the device is tested after each drop. All visible damage is noted for potential improvements in casing.
2. Vibration Test	The device is exposed to vibrations via a sub-woofer. This test is run 20 times and each iteration has a varying level of intensity. The deviation of the output compared with expected output is determined. Once the test is completed the internals of the device will be observed for any visible damage.
3. Temperature Test	The device is kept under a heating lamp and tested. Here, thermal noise effects are observed by noting the error in the A/D conversion. The temperature is then measured along with the output. Conversely, the device is cooled down using an air conditioner and tested. The A/D conversion error charts and the performance-temperature graphs are used to determine the device's tolerance to varied temperatures.

Table 4: Physical Tests

These tests cover a wide range of possible operating situations, and examine the physical (strength, durability), mechanical (resistance to vibration) and environmental properties of the system. By passing these tests, we are assured that the production Pace Maker units will function properly

All results obtained from the tests undertaken in this section are compared to the results obtained under near ideal conditions. This helps qualitatively determine the performance of the device under varying physical conditions.

6.2. Electrical Tests

Test	Description
1. Input Gain Extremities	The levels of input audio signals are varied over the range of the A/D converter. A/D operation is scrutinized to ensure proper conversion. The Output-Input Voltage charts are acquired to determine the predictable output for all possible levels of input gain.
2. Tempo Extremities	Signals that have both high and low tempos are used for this test. The determined signals are fed into the system and the varying numeric outputs are observed and recorded for determining output stability over the tempo

	range.
3. Complexity Levels	Up to 10 signals of varying complexity are used for this test. Each signal is fed into the system and the accuracy of the output is determined by comparing with known tempo values. The Deviation Error- Complexity plots are determined. This test identifies aspects of the algorithm that need improvement, and which styles of music prove troublesome for the beat-recognition software.
4. Input Isolation	Input isolation is used to determine system response to individual inputs. The trigger input, line input, and trigger mode selector are changed independently. The purpose of this test is not to acquire outputs but to "break" the device from a functional point of view. This helps isolate and resolve issues that may lead to customer complaints and recalls.
5. Noise Performance	Noise is added to the audio input. The amount of noise is varied to eventually overshadow the actual signal. The Output Deviation-Noise Level graphs are used to determine the noise tolerance of the system.

Table 5: Electrical Tests

6.3. Firmware/Algorithmic Tests

This section describes tests that are performed to ensure proper function of the software algorithms. Two sets of tests are completed: first, the algorithms are tested in the Simulink simulation environment for functionality. These tests are mainly driven by design requirements. Secondly, the DSP compiled code is tested on the DSP processor itself.

The basic DSP test procedure is as follows: first, samples are acquired from the line-input and validated to ensure that the A/D conversion is satisfactory and that memory management is functioning properly (this is done at a hardware level). Next, all blocks are unit-tested to isolate potential errors. This helps simplify and isolate problems that may be incurred in the complete software model. Finally integration tests are performed. Here the software core is put together and tested on the DSP platform. Outputs of certain subsystems are recorded and compared with the Simulink simulation.

In these tests, we are looking for certain subsystems to return exact results when compared to Simulink. However, due to fixed-point vs. floating-point issues, certain subsystems will not return entirely identical values, even though the final tempo output of the system might be identical.

7. Conclusion

The Pace Maker system has been designed for superior operation and ease of use. With a minimal number of inputs and outputs and only two front-panel controls, the UI designed for the Pace Maker gives the user all the required functionality to harness the power of this technology, without bogging him/her down with technical procedures.

This classic, simple device is destined to find a place in musical equipment history. Ideally suited for anyone interested in making rhythm-oriented music, the Pace Maker is a must have in every musician's setup.

Appendix A

A1: TMS320C6x Evaluation Board

Below is a detailed overview of the Texas Instruments TMS320C6x Evaluation Board:

The ‘C6x EVM hardware can be divided into 12 functional areas. This section proves an overview of each of these 12 areas:

- **DSP**: The ‘C6x EVM is built around the ‘C6210 DSP which operates up to 1600 MIPS with a CPU clock rate of 200 MHz.
- **DSP Clocks**: The ‘C6x EVM supports operation with two different onboard clock sources and two clock modes. As a result, the DSP can operate at four different clock rates.
- **External memory**: The ‘C6x EVM process one bank of 64K x 32, 133-MHz SBSRAM and two banks of 1M x 32, 100-MHz SDRAM. Additional asynchronous memory can be added with a daughterboard using the expansion memory interface. All external memory devices are byte-addressable.
- **Expansion interfaces**: The ‘C6x EVM provides external memory interface and external peripheral interface connectors that enable the use of a custom or third-party daughterboard.
- **PCI interface**; The ‘C6x EVM includes a PCI Local Bus Revision 2.1-compliant interface that enables host access to the onboard JTAG controller, DSP host port interface, and board control/status registers. ‘s PCI interface allows source debugging with the ‘C6x EVM without requiring an emulator, as well as host software access to all of the DSP memory space via the PCI bus. The ‘C6201/6701 DSP can also master the PCI bus to transfer data to and from the host memory
- **JTAG emulation**: this allows source debugging over the PCI bus without requiring an emulator or by using and XDS510 emulator when operating stand-alone on a desktop.
- **Programmable logic**: The ‘C6x EVM’s CPLD provides the board’s glue-logic and control/status registers.
- **Audio interface**: The ‘C6x EVM includes a CD-quality, 16-bit audio interface with stereo microphone and line-level inputs and a stereo line=level output. A multimedia audio codec is used that supports all popular sample rates from 5.5 kHz-48 kHz. The audio circuit includes an op amp based microphone preamplifier. Three 3.5-mm audio jacks are located on the board’s mounting bracket.
- **Power supplies**: The ‘C6x EVM uses voltage regulators to provide 1.8 V or 2.5 V for the DSP core; 3.3 V for the DSP I/O, memories, CPLD, and buffers; and 5 V for audio components. The PCI bus or external power connector’s 5 V is used for all other digital components. The PCI bus or external power connector’s 12 V is used for the input to the 5 V regulator.
- **Voltage supervision and reset control**: The ‘C6x EVM uses the voltage supervisor to monitor the board’s voltages and provide a board reset signal. The CPLD also includes logic related to reset control with the inputs from a manual reset pushbutton, the PCI controller, and software reset control signals.
- **User options**: The ‘C6x EVM supports user option control via 12 onboard DIP switches or with direct control by host software via the PCI bus. The user options include the boot mode, clock mode, clock select, JTAG select, and endian mode. Three user-defined option are also provided.
- **LED indicators**: The ‘C6x EVM provides three LED indicators. A single green LED is illuminated whenever 5 V is applied to the board. Two red LEDs can be used for user-defined status, with one located on the board’s mountain bracket and the other located at the top of the board.

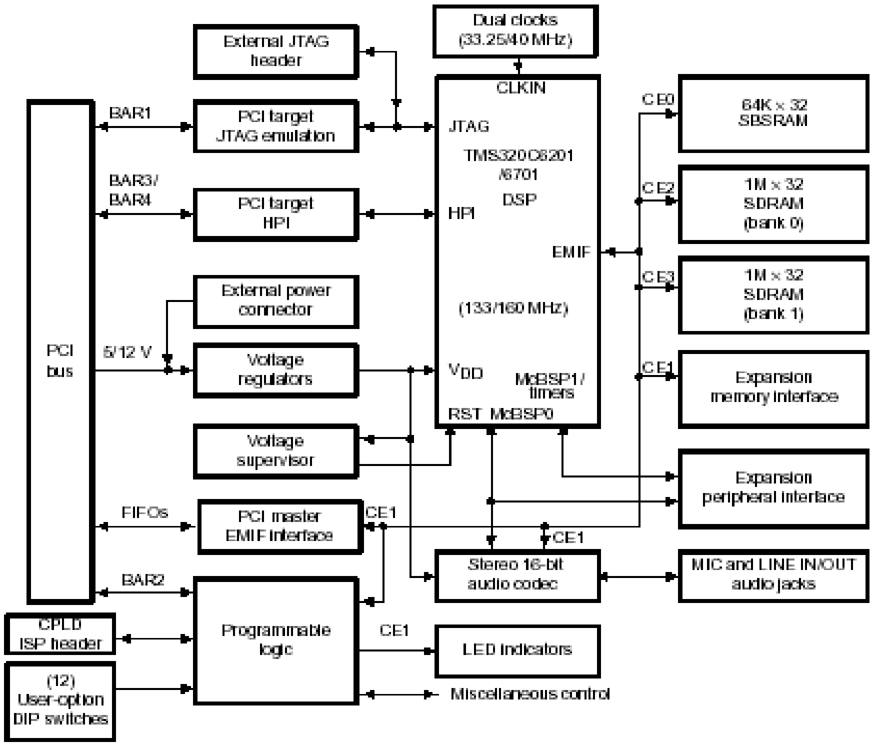

Figure A1: Block Diagram of the DSP Evaluation Board

TMS320C6x EVM Software Functional Overview:

The evaluation board software consists of host support software and DSP support software. The host support software supplied with the 'C6x EVM includes the following Win32 host utilities and libraries. The host utilities and host libraries run on an Intel compatible PC under either Windows 95 or Windows NT 4.0.

- **Board configuration utility**: This utility is used to reset and configure the board.
- **Code Composer**: Code composer is the new software debugger that is used to debug 'C6x software on the board.
- **EVM confidence test utility:** This utility tests the basic operation of the board.
- **'C6x COFF loader utility:** This utility is used to load and execute 'C6x software on the board.
- **EVM Win32 DLL**: The Win32 host libraries consist of a Windows 95 and a Windows NT version of evm6x.dll, which provides user software access for control and communication with the EVM board.

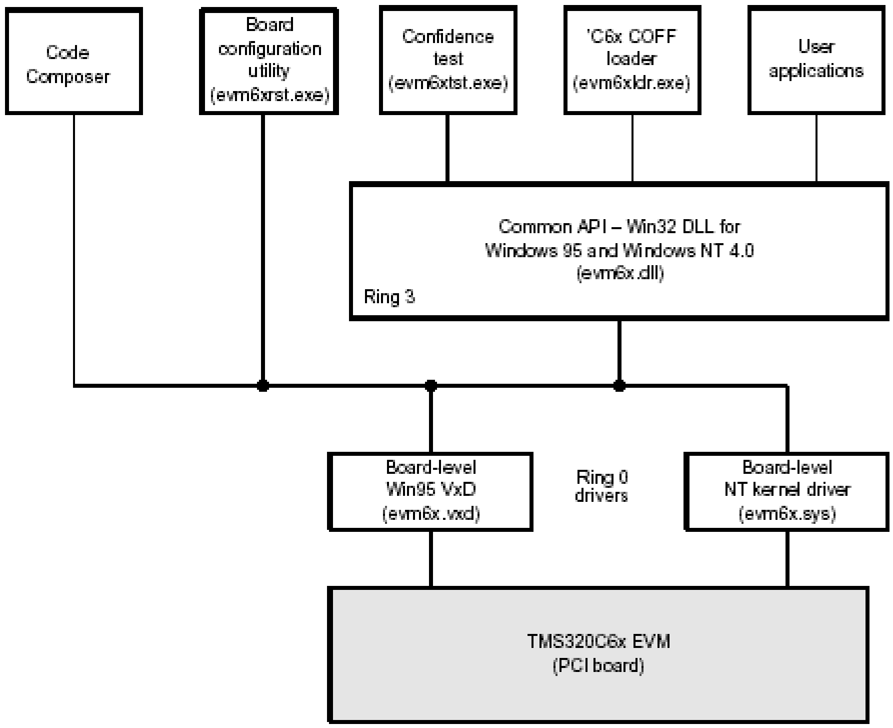

Figure A2: TMS320C6x EVM Host Support Software Block Diagram

A2: 3-Character Tempo Display

Pseudo code for the decoding of the 3-character tempo display:

```
begin
case last_four_bits is

--decode the value here from the truth table

when "0000" =>
value := "1111110";
when "0001" =>
value := "0110000";
… … …
when "1001" =>
value := "1111011";
when others =>
value := "1001111";        --displays an E for error

case first_two_bits is                --determine which LED to apply to
when "00" =>
aout <= value;
when "01" =>
bout <= value;
when "10" =>
cout <= value;
when others
```

The truth table for a decimal to seven-segment decoder is shown in Table 6 below.

Decimal	Binary	Seg a	Seg b	Seg c	Seg d	Seg e	Seg f	Seg g
0	0000	1	1	1	1	1	1	0
1	0001	0	1	1	0	0	0	0
2	0010	1	1	0	1	1	0	1
3	0011	1	1	1	1	0	0	1
4	0100	0	1	1	0	0	1	1
5	0101	1	0	1	1	0	1	1
6	0110	1	0	1	1	1	1	1
7	0111	1	1	1	0	0	0	0
8	1000	1	1	1	1	1	1	1
9	1001	1	1	1	1	0	1	1

Table 6 Truth table for seven-segment display

Appendix B

B1: References

Scheirer, Eric D. (**1998**). "Tempo and beat analysis of acoustic musical signals," in J. Acoust. Soc. Am. **103** (1), 588-601.

Goto, M., and Muraoka, Y. (**1999**). "Real-time beat tracking for drumless audio signals: Chord change detection for musical decisions," in Speech Communication **27**, 311-335.