THE DEVELOPMENT OF A PIANO-RECORDER SYSTEM

By Bernt W. Damm

Thesis submitted in partial fulfilment of the requirements for the Master Diploma in Technology to the department of Electrical Engineering (light current) at the Cape Technikon.

CAPE TOWN

SOUTH AFRICA

FEBRUARY 1993

DECLARATION

I declare that the contents of this thesis represent my own work and the opinions and ideas contained here are my own. It has not been submitted before for any examination at this or any other institute.

B.W.Damm

(Signature)

ABSTRACT

This thesis describes the development and design of a piano-recorder system. This system makes it possible to record the notes played on a piano onto a computer disk. The records can then be used for the manufacturing of pianola rolls.

OPSOMMING

Hierdie verhandeling beskryf die ontwikkeling en ontwerp van 'n Klavier opnemer stelsel. Hierdie stelsel maak dit moontlik om die note wat gedurende 'n klavierstuk gespeel word op n rekenaar skyf te stoor. Hierdie opnames kan dan gebruik word vir die vervaardiging van Pianola rolle.

ACKNOWLEDGEMENTS

I would especially like to thank my parents for their and moral financial support during the development of this project.

I would also like to thank Mr P.H. Kleinhans of the Cape Technikon who acted as internal project leader and for editing this manuscript.

I also want to thank my patient friends and colleagues at the Cape Technikon who supported me in many ways during this project.

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1. INTRODUCTION

This thesis describes an investigation into the design and implementation of a piano-recorder system.

The design described in this thesis is aimed at revolutionising the manufacturing process of pianola-rolls (see Chapter 2 for more details on the pianola and rolls.)

The main objectives of this research project were:

(i) To design and construct a system which would make it possible to record the physical keys pressed on a piano.

(ii) To design and write software that would enable a PC to read these recorded notes from the system and store them in a file on disk for further processing.

All the relevant design criteria for the above objectives evolved from the authors personal ideas and experiments. Since no data for a similar system could be located , it is assumed that this design approach is unique.

Firstly to fulfil the above requirements, the following systems were considered and investigated:

(i) A mechanical-electrical recording system which would operate with pencils and solenoids. This would draw pilot lines onto a specially prepared paper-roll where the perforations would be cut.

(ii) A Midi (Musical instrument digital interface) system which could be linked from the piano to the computer.

(iii) The 'PIANO-RECORDER' which is the system described in this thesis.

The report commences with chapter 2 which provides a brief background on the pianola and its rolls. Chapter 3 discusses the various systems considered, chapter 4 gives a basic description of the actual design. Chapter 5 deals with the switch system mounted in the piano, chapters 6, 7, 8, 9 and 10 describe the hardware circuitry and Chapter 11 discusses the software development. Chapter 12 deals with problems encountered and chapter 13 describes the installation procedure for the system. Lastly, chapter 14 rounds off the thesis with a brief description of possible future developments around the piano recorder system.

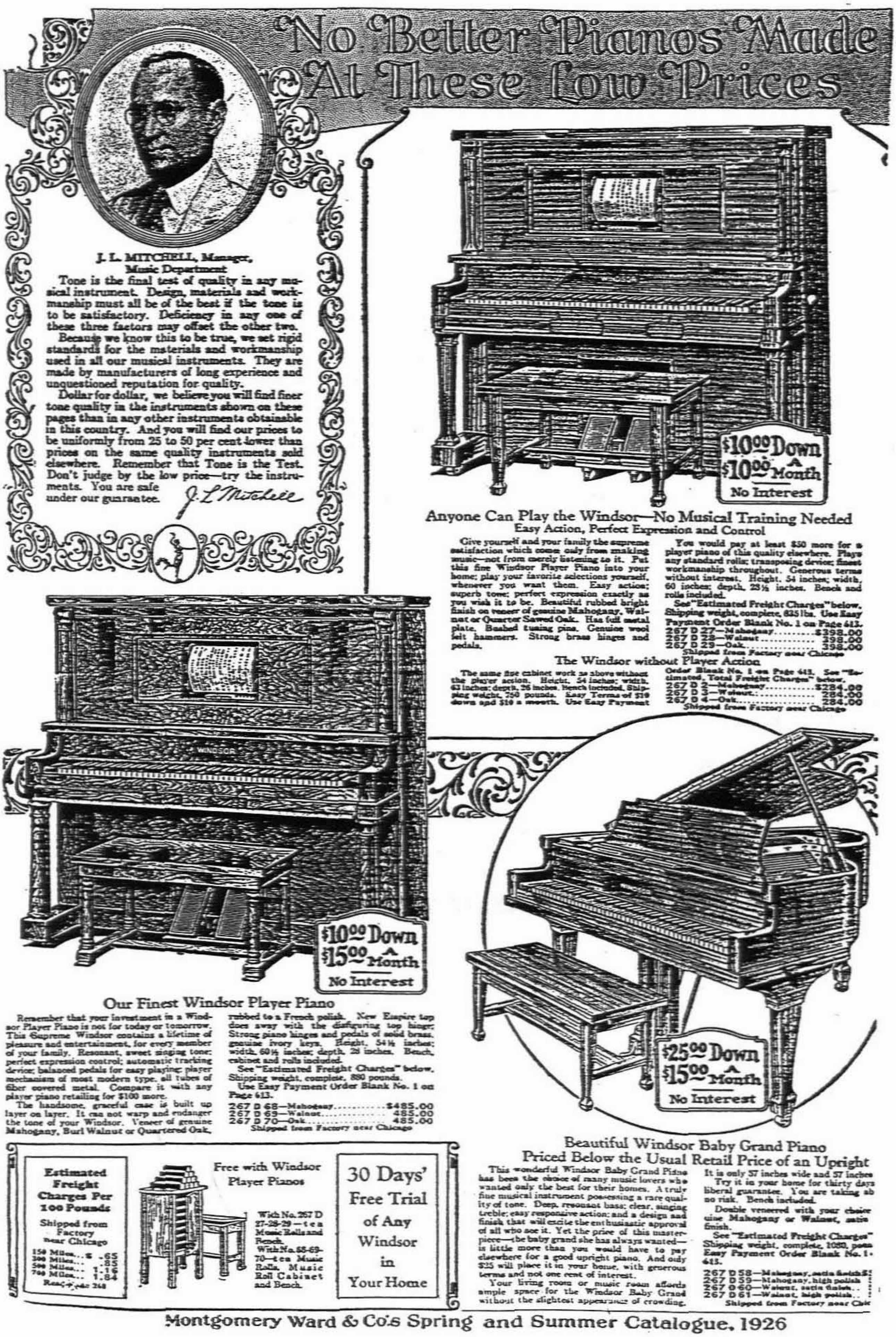
2. ABOUT THE PIANOLA AND ITS ROLLS

The author found that most people of today do not know what a pianola is. Therefore this chapter has been included to provide the reader with some additional information about the pianola and its rolls.

2.1 THE PIANOLA (INTRODUCTION)

The pianola is a piano to which is added complicated mechanical machinery, enabling it to play music encoded on a paper roll. This playback is accomplished by means of a pneumatic system (see figure 2.1) which operated the piano hammers. The correct name for this instrument is a 'Player Piano' which means a piano with a player, all in the same casing. These instruments were extremely popular during the 1910's and 1920's. The pianola is one of the predecessors of the gramophone and radio. Together with the fairground organ it was the most popular of the very few sources of music (except live musicians) available during that era.

Although thousands were made, only a few of these instruments have survived until today. Most of them were simply replaced by radios and juke boxes. This makes the pianola a collectors item which should be preserved for future generations.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You would pay at least $50 more for a player piano of this quality elsewhere. Plays any standard rolls; transposing device; finest workmanship throughout. Generous terms without interest. Height, 54 inches; width, 60 inches; depth, 23½ inches. Bench and rolls included.
See "Estimated Freight Charges" below. Shipping weight, complete, 835 lbs. Use Easy Payment Order Blank No. 1 on Page 613.
267 D 27—Mahogany..........$398.00
267 D 28—Walnut.......... 398.00
267 D 29—Oak.......... 398.00
Shipped from Factory near Chicago
The Windsor without Player Action
The same fine cabinet work as above without the player action. Height, 54 inches; width, 63 inches; depth, 26 inches. Bench included. Shipping weight, 750 pounds. Easy Terms of $10 down and $10 a month. Use Easy Payment Order Blank No. 1 on Page 613. See "Estimated, Total Freight Charges" below.
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See "Estimated Freight Charges" below. Shipping weight, complete, 880 pounds.
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267 D 68—Mahogany..........$485.00
267 D 69—Walnut.......... 485.00
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Priced Below the Usual Retail Price of an Upright
This wonderful Windsor Baby Grand Piano has been the choice of many music lovers who wanted only the best for their homes. A truly fine musical instrument possessing a rare quality of tone. Deep, resonant bass; clear, singing treble; easy responsive action; and a design and finish that will excite the enthusiastic approval of all who see it. Yet the price of this masterpiece—the baby grand she has always wanted—is little more than you would have to pay elsewhere for a good upright piano. And only $25 will place it in your home, with generous terms and not one cent of interest.
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Try it in your home for thirty days liberal guarantee. You are taking no risk. Bench included.
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267 D 58—Mahogany, satin finish
267 D 59—Mahogany, high polish
267 D 60—Walnut, satin finish
267 D 61—Walnut, high polish
Shipped from Factory near Chicago
Estimated Freight Charges Per 100 Pounds
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150 Miles...$ .65
300 Miles... .85
500 Miles... 1.16
700 Miles... 1.84
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With No. 68-69-70—ten Music Rolls, Music Roll Cabinet and Bench.
30 Days' Free Trial of Any Windsor in Your Home
Montgomery Ward & Co's Spring and Summer Catalogue, 1926

Figure 2.1

2.2 THE PIANOLA-ROLL

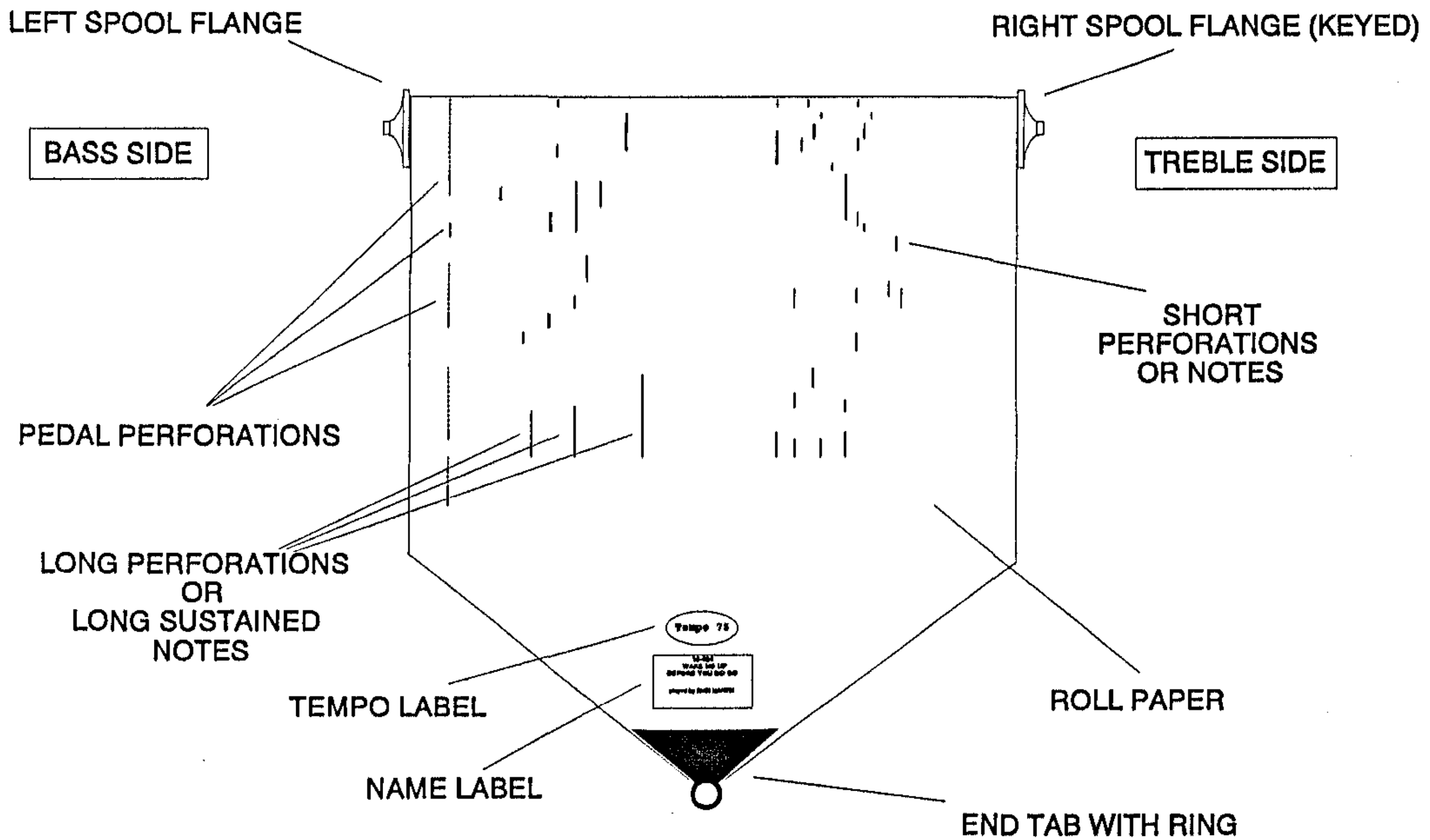
As mentioned, the instrument plays the music encoded on a paper roll. The notes played are encoded as perforations at specific horizontal positions across the paper. The correct duration of the notes is controlled by extending the perforations into slots of the desired length along the length of the paper. Pianola rolls were available in different sizes, the most popular being the standard 88 note roll (Please refer to Figure 2.2). This roll is 11.25" wide. Along this width, there are 89 reserved spaces for perforations. 88 are for all the available notes of a piano and one is for the sustain pedal of the piano. It can thus be said that the roll is encoded digitally. A perforation in the paper means a '1' or 'ON' while blank paper means a '0' or 'OFF'. These codes are read from the roll by means of a tracker bar over which the roll travels.

2.3 OPERATION OF THE PNEUMATIC PLAYER ACTION

Figure 2.3 shows the basic layout of the pneumatic player action as found in many pianolas.

The first step to operate the pneumatic system is the insertion of a music roll in the spool box. This will cause all the holes in the tracker bar to be sealed off, thereby preventing outside air to enter the pneumatic system.

FIGURE 2.1

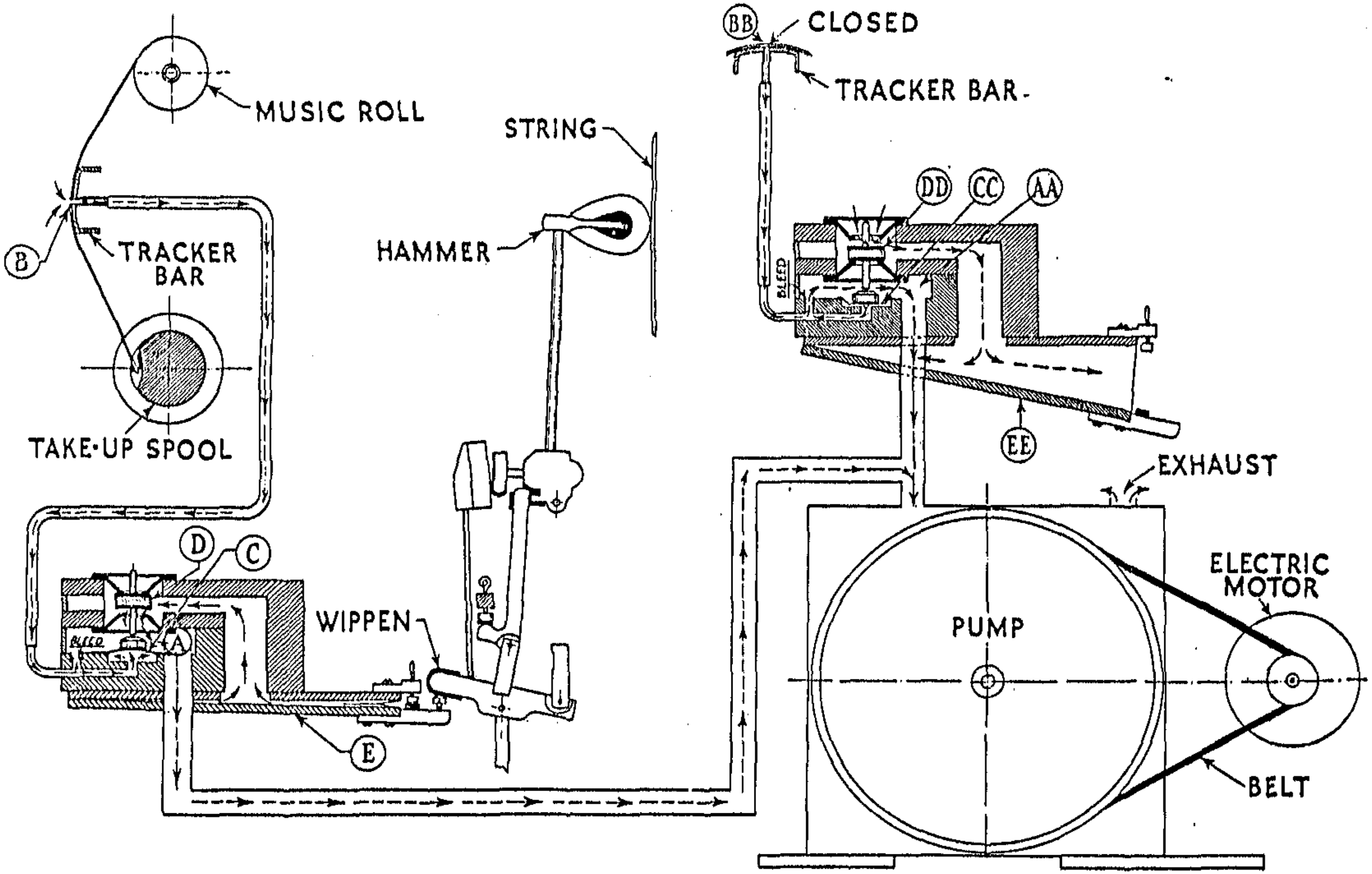


Basic layout of a standard 88-note pianola roll

Next, the vacuum pump must be brought into operation. The pump can be of the electrical driven type (rare) or of the foot operated type with pedals. The function of the pump is to lower the pressure inside the system substantially so that the valves and pneumatics will operate properly. In the case of "BB", the tracker bar hole is closed by the music roll paper, allowing the vacuum in the system to be present right up to the tracker bar. The tracker bar tube is connected to the vacuum supply chamber "AA" via a small bleed. The size of this bleed is very important for the proper operation of the pneumatic system. The valve "DD" is seated onto its bottom seat, allowing outside air to enter the striker pneumatic "EE". This causes the pressure inside the pneumatic to be equal to the outside pressure. Therefore the pneumatic will be open, as shown in "EE".

To play a note on the piano, the pneumatic must close. This is achieved by a perforation in the music roll which will expose a hole in the tracker bar as shown in "B". Now , outside air will rush into the tracker bar tube leading to the bleed and the underside of the leather pouch "CC". Outside air enters "B" in a larger quantity than can be removed via the small bleed into chamber "A". This means that the pressure above the leather pouch (chamber "A") is much lower than the pressure below the pouch. Therefore, because of the property of atmosphere to equalize itself in space, the thin leather pouch is pushed upwards towards chamber "A", thereby lifting

DIAGRAM OF PNEUMATIC PLAYER OPERATION



the valve "D".

The result is that valve "D" now seats against its top valve seat, cutting off the outside air entrance and connecting the striker pneumatic "E" to the vacuum chamber "A". The pressure in the pneumatic will drop to the same pressure as in chamber "A". This will cause the pneumatic to collapse (close), its moving leaf being pushed up by the outside atmosphere. This happens with such a force that the piano action wippen raises with enough force to cause the hammer to hit the string and sound the note. When the tracker bar hole is closed again by the roll paper, the pressure in the tube and below the leather pouch will drop back to the same level as in chamber "A". This will cause the leather pouch to drop along with the valve, thereby allowing the valve to return to its bottom seat again as in "DD".

2.4 THE REPRODUCING PIANO (INTRODUCTION)

A reproducing piano is capable of perfectly reproducing an artist's playing style. This means that not only the same notes struck can be played back (as in an ordinary player piano) but also the correct striking force (volume) for each note is faithfully reproduced. This is accomplished by adding a very complicated expression system to a basic player piano. Such a system changes the vacuum level applied to the little pneumatics "E" for different striking forces, as required. These changes can be accomplished fast enough to play any successing notes at a different volume, just as a live pianist would do. The codes for the expression system are placed on the special rolls, normally at the left and right sides.

There were four major systems available during the player piano era. These were:

(i) The 'Duo-Art' manufactured in USA and Great Britain by the Aeolian Company.

(ii) The 'Ampico' manufactured in USA by the American Piano Company.

(iii) The 'Welte-Mignon' manufactured originally by M. Welte and Sons in Freiburg, Germany. Later a modified version was also marketed under license by the Auto Pneumatic Action Company of New York.

(iv) The 'Hupfeld-Triphonola' manufactured by the Hupfeld company in Leipzig, Germany.

All these systems were available in different piano makes to suit the customer's budget or preference. Also the different makes used different rolls which were not interchangeable with the other systems.

Today, the reproducing piano is the only means by which we can hear the original work of world famous artists like Grieg and Debussy (to mention a few) who lived before the age of the gramophone. The reproduction ability of the reproducing piano is so good that a lot of its music has been recorded onto records in hi-fi stereo over the past years.

Some of these instruments are very rare today because they were very expensive originally. Also they are extremely difficult to restore and many of them were converted to ordinary pianos by simply removing all the pneumatic systems. Today they are prized and cared for by collectors all over the world, making music once again.

2.5 THE NEW GENERATION OF SELFPLAYING PIANOS

The pianola or selfplaying piano is not dead. New developments are still being made. Yamaha offers a range of selfplaying pianos which operate with a compact disk and solenoids. At the time of research for this project, a friend of the author reported to have seen four or five of these pianos at Harrod's in London, one on each floor in the staircase and playing all day long.
During December 1991 there was a concert held in Den Haag with six computer-driven grand pianos. These included:

(i) One old Bechstein grand piano with a later added electronic Marantz system converted for Midi use by the Netherland Institute For Electronic Music STEIM.

(ii) One Steinway grand piano from Magic Music with a later added new Autoklav system.

(iii) One Yamaha disc piano.

(iv) One Bösendörfer model 290SE concert grand piano.

(v) Two grand pianos, each with custom made selfplaying systems made by Trimpin, a German/American elctronic constructor.

These instruments were operated from computers by means of Midi. They were demonstrated and evaluated by many different people. However, the author of the article (Mohr,1992(55),33) from which a lot of this information was taken claims that all the modern technology employed in these pianos does still not really outperform the original pneumatic instruments from the 1920's. The above mentioned Bösendörfer piano for instance is capable of playing each note with 1018 different striking forces. Is this really necessary? Experiments carried out at the Ampico factory during the 1920's have shown that the human ear can distinguish only about seven levels of volume on a piano. This has been verified by this author by simply trying it out on a piano.
Also, the new instruments cannot reproduce performances of original artists who have lived before this era.

The original pianos are also much more fun (personal opinion of this author) because everything works mechanical and one can see the keys of the piano as well as the roll move.
It is perhaps because of this that the french firm 'Pneumatique Contemporaine' has recently started with the construction of Duo-Art reproducing pianos which work pneumatically again.
However, This proves that the selfplaying piano is not forgotten.

3. THE SYSTEMS INVESTIGATED

This chapter outlines the advantages and disadvantages of the systems mentioned in chapter 1.

3.1 MECHANICAL-ELECTRICAL RECORDING SYSTEM

This type of system was investigated first as this is the way in which some of the original master-rolls were recorded back in the 1920's. Such a system would consist of 89 little solenoids with their plungers connected to pencils and the roll-paper passing through beneath the pencils. The recording-piano's switches control each solenoid. If a key is pressed, the corresponding solenoid pushes the pencil onto the paper of the master-roll, thereby drawing a line as the paper moves on. When the key is released, the solenoid is turned off and the pencil is pulled away from the paper by means of a small spring.

A variation of this system is still used by QRS Music Rolls, Inc. in Buffalo New York. This company still manufactures pianola rolls. The only difference is that their marking machine uses pneumatics instead of solenoids and steel styluses and carbon paper are used instead of pencils to make the marks on the paper. Their machine dates from 1905 and is connected to a Mellville Clark Grand Piano (Music Box Society International, 1974).

3.1.1 ADVANTAGES

The only advantage that could be found for this system was that the electrical wiring is extremely simple. (Just a switch which turns on and off a solenoid for each note).

3.1.2 DISADVANTAGES

(i) The mechanical layout of the solenoids is very complicated as the solenoids are relatively large, they would have to be staggered in order to fit the pencils in the correct spacing.

(ii) The recording machine would be extremely bulky.

(iii) The system would use an enormous quantity of electricity.

(iv) The pencils used, would have to be sharpened too often.

3.1.3 CONCLUSION

This system would not be an economic nor satisfying solution to the problem at hand. It would simply be too expensive and bulky. Also it would not be a new approach.

3.2 MIDI SYSTEM

This system would consist of a MIDI interface connected to the switches in the recording-piano. The codes of the pressed keys on the piano would be sent to the PC as MIDI data for recording onto disk and processing. This type of system is used widely by keyboards but is less popular for pianos and no information could be found about its use for the manufacture of pianola rolls. Research showed that Carl Sauter Pianofortefabrik in Spaichingen, Germany introduced a Midi compatible piano in 1988 called 'Picco'. This has nothing to do with the recording of pianola-rolls except that this type of piano could be used as recording piano in a Midi system. Other firms also offer such pianos and there are also kits available which can be mounted into an ordinary piano to make it Midi compatible.

3.2.1 ADVANTAGES

(i) The system would be very versatile. The recorded masters could be played back on any Midi-controlled keyboard.

(ii) The interface could be purchased commercially, no designing would be required.

3.2.2 DISADVANTAGES

A Midi system might be too slow to transmit the data of a large chord spread over 88 piano keys without a delay between the notes. This is because MIDI is transmitted by means of serial data running at a speed of 31250 pulses per second. 10 such pulses are required per note played. Therefore it takes 0.32 milliseconds until the next value can be sent. These delays are quite acceptable for normal ten-finger playing but many pianola-rolls are recorded with chords where up to 40 notes are pressed at once. This would result in a delay between the first and last note of such a chord of almost 13 milliseconds. Since such delays are not acceptable to the author for the precise recording of a pianola roll, special Midi delay lines would have to be used to compensate for this problem.

3.2.3 CONCLUSION

This system could be a good option but the equipment would have to be carefully set up for correct operation. This would require quite complicated software. It would also be very expensive as Midi equipment is not cheap.

3.3 PROPOSED PIANO-RECORDER SYSTEM

This system would have to be specially designed for the task at hand. It would be named PIANO-RECORDER. (Refer to chapter 4 for a detailed description and design considerations).

3.3.1 ADVANTAGES

This system could be optimized specifically for the task of recording pianola rolls. It would not require any elaborate mechanical devices such as moving paper and solenoids. Neither would special delay lines and software processing be required to synchronise the data. The whole system would also not be larger than a average PC.

3.3.2 DISADVANTAGES

To design such a system would require far more effort and careful consideration than any of the other approaches in order to make it work properly.

3.3.3 CONCLUSION

Because this system can be made specifically for the task and considering all the disadvantages of the other systems evaluated, this one would appear to be the most logical option.

4. PIANO-RECORDER OUTLINE

This chapter describes the overall layout of the piano-recorder and the design considerations. Refer to FIGURE 4.1 for a block diagram.

4.1 DESIGN CONSIDERATIONS

After careful consideration, it was decided that the piano-recorder system should have the following specifications:

(i) The system should be able to record the piano in a parallel mode to avoid any possible delays between keys pressed simultaneously.

(ii) The system must be able to record 88 piano notes as well as the pedal. There should still be room for some expansion, like the recording of a metronome (a device giving a constant tempo for music).

(iii) The system must be able to scan the piano fast enough in order not to miss any very fast notes.

(iv) The speed of the parallel scanning of the piano must be variable so that the recorded file can easily be matched to the speed that the actual master roll would run in the piano.

(v) The system must be able to record the piano for at least twelve minutes, so that even long classical music pieces could be recorded.

4.2 IMPLEMENTATION OF DESIGN CONSIDERATIONS

The considerations mentioned in 4.1 were implemented as follows:

(i) In order to record the piano in parallel mode, a wide memory bank was used, capable of reading all the 88 piano keys at once, as well as the pedal and with some reserved space for later expansion.

(ii) To record all piano keys and pedal, the memory bank must be (88+1) = 89 bits wide. For practical reasons, it was decided to make the memory bank 96 bits wide. This would ensure enough space for expansion.

(iii) To determine how often per second the system must scan the piano (scans/second), in order not to skip very fast notes and also not to waste valuable memory space, some literature study and practical research had to be done. According to 'Klavier-Praktishes Handbuch' (Uchdorf, 1985) a properly regulated double-repetition grand piano action, should be able to repeat a single note at least 10 times per second. However, the author of this thesis found from experience as a pianist that a it is possible to play five different notes in succession, with one hand, at leat two to three times as fast. Therefore, in order not to loose these minute time differences, the minimum scanning rate must be high enough to ensure that they are not lost, even when very fast music is being recorded. On the other hand, the scanning rate should be as low as possible, so that optimum use of the memory is made. The minimum scanning rate should therefore be according to the Nyquist sampling theorem at least twice the maximum repetition rate. This was calculated as 2*(10*3)= 60Hz. A master clock running at 70Hz was chosen. Figure 4.2 shows the relationship between the recording speed and the growth of the filesize stored on the PC disk.

(iv) The pianola has a 'TEMPO' control, which must be adjusted to correspond with the tempo label printed on each roll, in order to play the roll at the correct speed. Therefore, the master clock board was designed with a rotary selection switch, which makes it possible to record at different speeds.

(v) The minimum memory required for a recording of 12 minutes is given by the product of the scanning rate and the duration of the recording in seconds. This results in (70*60*12)= 50000 locations (of 96 bits each). The memory was chosen to be 64kB. This would allow for a maximum recording time of 15.6 minutes.

Figure 4.1 shows the relationship between the recording speed and the maximum recording time.

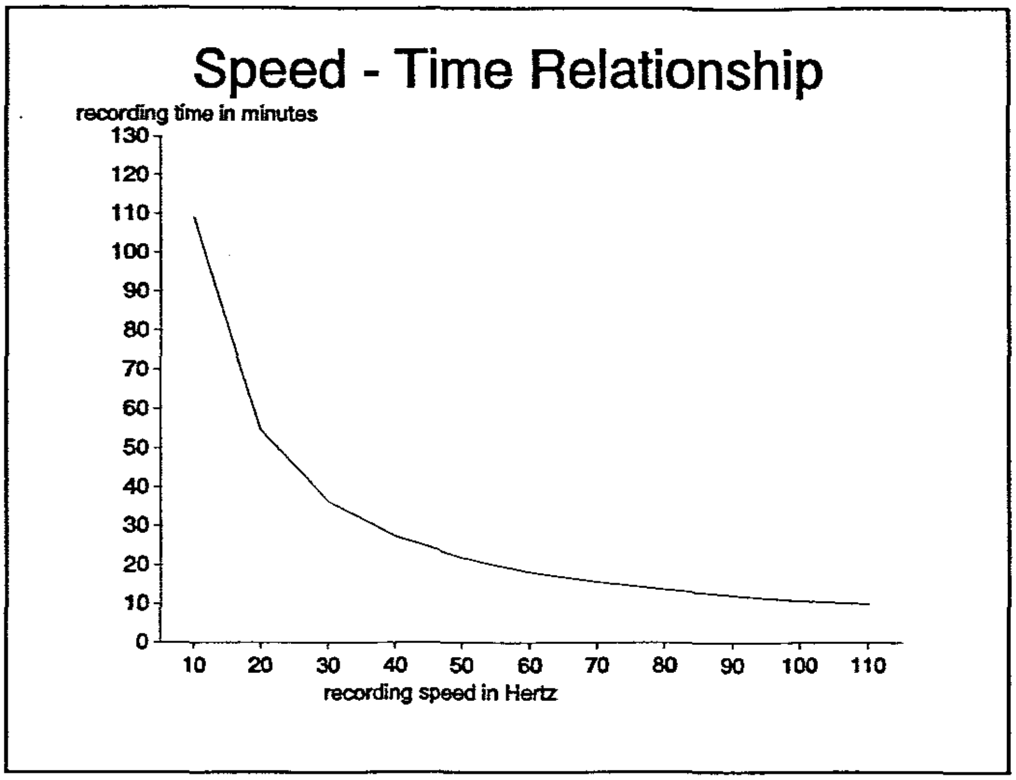


FIGURE 4.1

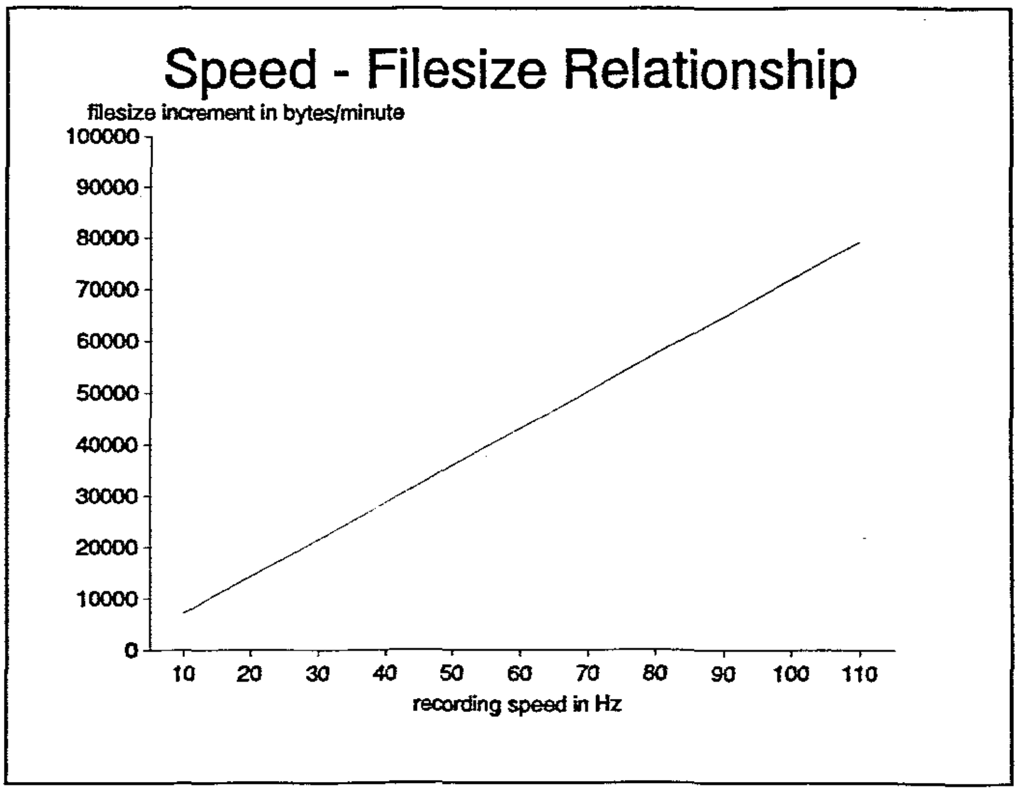


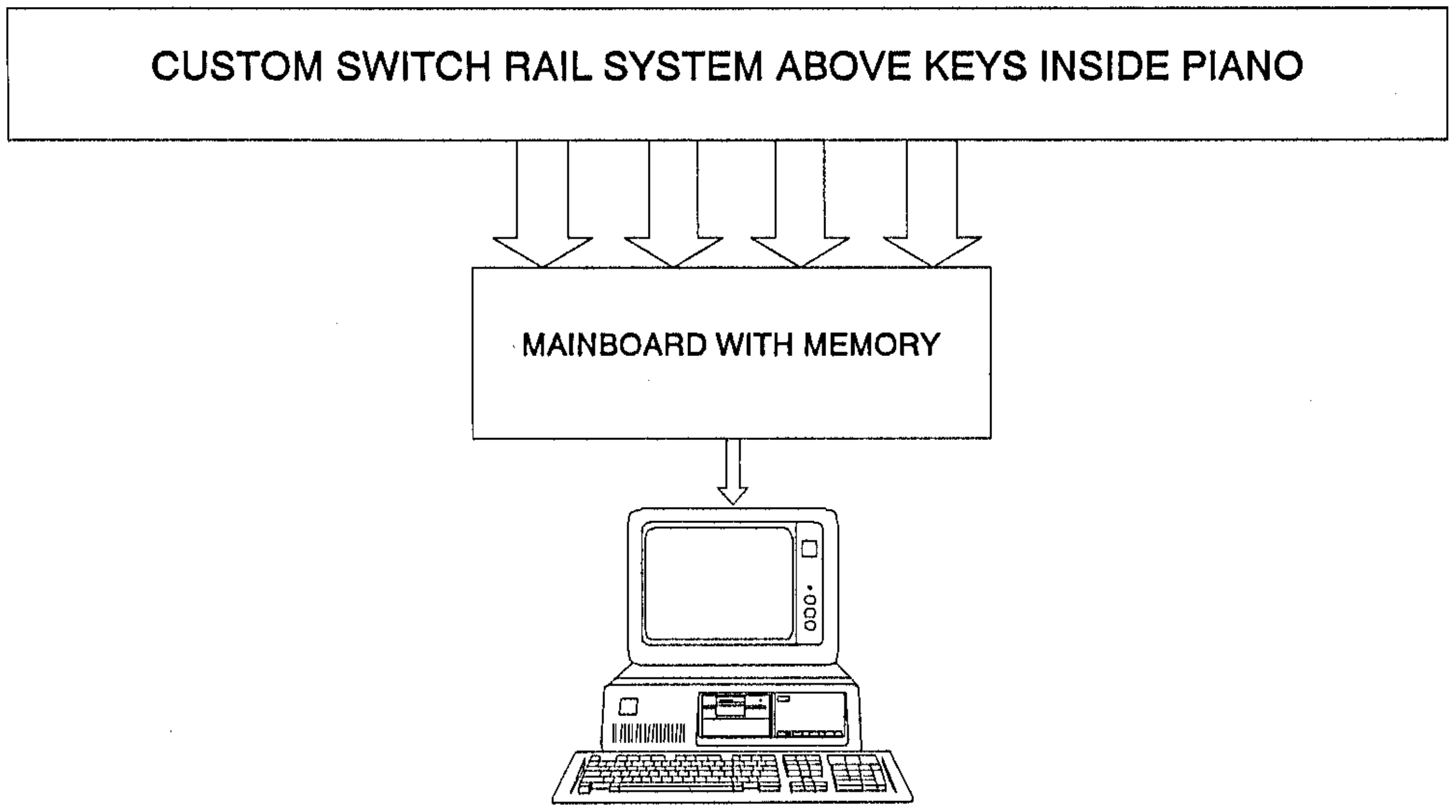
FIGURE 4.2

4.3 BASIC SYSTEM LAYOUT

The final system consists of three main parts (see Fig. 4.1), a switch rail built into a piano, the main control unit and an interface for a personal computer.

The switch rail supplies logic signals from the piano keys as they are pressed and released. These signals travel via four ribbon cables to the main control unit. This unit stores the signals in its memory bank (64k by 96 bits). The recording speed can be chosen by means of a selector switch with six calibrated options. After the recording is complete, a switch is flicked by the operator. The data can then be read at any convenient speed from the main control unit memory into the PC for further processing and storage on disk.

FIGURE 4.3



BASIC SYSTEM LAYOUT

5. SWITCH-RAIL

Refer to drawing No. 01 Appendix A for basic schematic diagram of the switch-rail.

In order to record the pressed keys of the piano, a custom made switch-rail had to be designed to fit into the piano.
This rail is manufactured from wood and it fits inside the piano above the keys. No alterations like holes etc. had to be made to the piano at all to fit the switch-rail. It can simply be installed or removed within a few minutes.
The switches on the rail are mounted onto printed circuit boards, accurately spaced. Each board holds 12 switches or one octave. The last board is sized to hold only 4 switches.
The switches are linked to the recording system by means of four DB25 connectors.
Any further elaboration of this design would not be in the interest of the author.

6. ADDRESS DECODER CARD

Refer to drawing No. 02 Appendix A for the complete address decoder schematic diagram.

6.1 FUNCTIONAL DESCRIPTION

The address decoder card is the interface between the personal computer and the Piano recorder mainboard.
The card is decoded to operate on the standard PC prototype card addresses from 300 hex to 30B hex. Its function is to supply a low and high address to the Piano-recorder mainboard and to read 12 values (8 Bit each) from the mainboard at the specified address. All these functions must be controlled by software from the PC.

6.2 HARDWARE DESCRIPTION

6.2.1 DISABLED STATE

When the address decoder card is not accessed via software from the PC, on any of its functional addresses, U3A pin 3 is high, U3B pin 6 is high, U2 is disabled, U4 is disabled via R1 and ADD LO as well as ADD HI on P1 are low. Therefore no data is transferred to or from the mainboard.

6.2.2 READ FROM 300 HEX - 30B HEX

For IO read operations from 300 hex to 30B hex, U3A pin 3 goes low and U3B pin 6 remains high. U2 is thus enabled which

results in lines S0 to S11 to go low when their corresponding numbers from 0 hex to 0B hex appear on A0-A3.
U4 is enabled via D2 and its direction is switched from B to A, resulting in data from D00 to D07 to be transferred onto the PC-bus D0-D7. ADD LO and ADD HI remain low for any read operations.

6.2.3 WRITE OF LOW ADDRESS AT 300 HEX

An IO write operation at address 300 hex will result in the low address being written to D00-D07. This is done in the following way:
U1 pin 19 goes low, U3B pin 5 goes low (-IOW), resulting in U3B, which is a OR gate, pin 6 going low too.
This enables U4 which is a Tri-state buffer. U4 will be in the data sending mode (from A to B) because U3A pin 3 remains high.
This causes data from the PC-bus (D0-D7)to be sent onto D00-D07 of P1.
U2 is disabled because pin 18 and pin 19 remain high.
The ADD LO pin of P1 will go high because U3C pin 9 and 10 are both low and U5C inverts the low output from U5C pin 8.
The ADD HI pin of P1 remains low because U3D pin 12 goes high for a low on A0.

6.2.4 WRITE OF HIGH ADDRESS AT 301 HEX

An IO write to 301 hex will result in the high address being written to DO0-DO7. This operation is exactly the same as for the low address part at 300 hex, except for A0 now being high.
his results in U3C pin 8 going high and U3D pin 11 remaining low. The effect is that ADD LO will now be low and ADD HI will go high. The data is still transferred from D0-D7 to DO0-DO7.

7. MAINBOARD

Refer to Drawing No. 03 Appendix A for the schematic diagram of the mainboard.

7.1 FUNCTIONAL DESCRIPTION

This board contains the memory-bank and basically controls its read and write operations. The board has 3 controls, a 'RESET' button, a 'START/STOP' switch and a 'RECORD/READ' switch. There is also an Led which comes on when the memory-bank is full. When the 'RECORD/READ' switch is in the 'RECORD' position, the mainboard is ready to record the notes from the piano. After 'RESET' is pressed, the 'START/STOP' button can be switched to 'START'. Now the board starts counting through the RAM addresses at a speed determined by the master-clock board (see chapter 8). After every address increment, a write to that address in the RAM occurs. This means that 96 bits of data from the piano are stored because the RAM is 64K x 96. After completion of the recording, the 'START/STOP' switch must be switched to the 'READ' position. The stored data can now be read from the memory into the PC, 8 bits at a time. To accomplish this, the PC must first supply a low and high address. Then it can read 12 values from the mainboard memory-bank at that address (12 x 8 = 96 bits).
Refer to table A for specific IO addresses for the Address write and data read operations.

7.2 HARDWARE DESCRIPTION

7.2.1 WRITE (RECORD) OPERATION

SW1 must be in the 'RECORD' position and SW2 must be in the 'START' position for this operation.
When 'RESET' is pressed, U3 and U4 will start counting from 0 upwards. U7 and U8 are disabled via SW1b and U5 and U6 are enabled. This causes the outputs of U3 and U4 to appear on the RAM address bus.
The clock input [CLK] goes through U2A onto pin 10 (Clk) of U3, causing it to count. U4 is cascaded onto U3, its Clk being driven from U3.Q12. The [CLK] signal also goes via U1A and U2B onto the [-WE] line of the RAM bus. Because U1A inverts the signal, the [-WE] line will go low half a clock cycle after the address is increased.
U1B inverts the [A15] line to become an additional [-A15]. These two lines are used to select between the lower and higher 32K in the memory-bank (see chapter 7 for memory-board details).

7.2.2 READ OPERATION

For this operation, the 'RECORD/READ' (SW1) switch must be in the 'READ' position and the START/STOP (SW2) switch should be in the 'STOP' position but does not have to be, as SW1a overrides it.

P1 is the connection to the address decoder card in the PC (see chapter 5 for address decoder details). S0-S11 select the 12 different RAM boards during the read operations. These 12 lines are driven directly from the address decoder card and drive the [-READ] lines of the RAM boards. U7 and U8 are enabled by SW1b. This causes their output to appear on the RAM address bus. U7 latches the high address when P1 pin 9 is pulsed high from the PC card. Similarly U8 latches the low address when P1 pin 21 is pulsed high.

The outputs of U3 and U4 may be in any state as they are disabled from the RAM address by U5 and U6 which are Tri-state buffers. The clock input [CLK] is also disabled by U2A and U2B. Therefore U3 and U4 do not count and the [-WE] line stays high.

It can thus be seen that the address supplied to the RAM address bus comes from the PC through U7 and U8. The data from the RAM comes via DO0-DO7 onto P1 and to the PC.

LINE NAME	ACTIVE	HEX ADDRESS	FUNCTION	DB25 PIN
DO0	X	---	DATA	22
DO1	X	---	DATA	10
DO2	X	---	DATA	23
DO3	X	---	DATA	11
DO4	X	---	DATA	24
DO5	X	---	DATA	12
DO6	X	---	DATA	25
DO7	X	---	DATA	13
LO ADDR.	1	I/O 300 WRITE	A0 - A7	21
HI ADDR.	1	I/O 301 WRITE	A8 - A15	9
S0	0	I/O 300 READ	NOTES 17-24	19
S1	0	I/O 301 READ	NOTES 9-16	6
S2	0	I/O 302 READ	NOTES 1-8	18
S3	0	I/O 303 READ	NOTES 41-48	5
S4	0	I/O 304 READ	NOTES 33-40	17
S5	0	I/O 305 READ	NOTES 25-32	4
S6	0	I/O 306 READ	NOTES 65-72	16
S7	0	I/O 307 READ	NOTES 57-64	3
S8	0	I/O 308 READ	NOTES 49-56	15
S9	0	I/O 309 READ	NOTES 89-96	2
S10	0	I/O 30A READ	NOTES 81-88	14
S11	0	I/O 30B READ	NOTES 73-80	1
N/C	-	----------------	----------------	8
GND	-	----------------	GROUND	7
GND	-	----------------	GROUND	20

LAYOUT OF PC I/O ADDRESSES AND THEIR FUNCTIONS

Table 1

8. MEMORY BOARDS

Refer to drawing No. 04 Appendix A for the schematic diagram of the memory boards.

8.1 FUNCTIONAL DESCRIPTION

When the mainboard is in the 'RECORD' mode, Data is written from the piano through the note bus of each board into the memory. When the mainboard is in the 'READ' mode and the memory is accessed by the PC, data is read from the accessed memory board onto the common system bus and to the PC.

8.2 HARDWARE DESCRIPTION

There are 12 identical memory boards, each with an edge connector that plugs into a slot on the mainboard. Refer to drawing No. 05 for slot pinouts. Each slot connects to the common address bus (A0 - A15, -A15), the common system data bus (DO0 - DO7), a common write line (-WE), a separate read line (Sx) and a separate note bus, leading to 8 switches in the piano.

8.2.1 WRITE (RECORD) OPERATION

The read lines (Sx) will remain high during the record operation. This disables U3, preventing data from the memory board appearing on the common data bus. As the -WE line is pulsed low by the mainboard, U4 is enabled and data directly from the 8 piano notes appears on the RAM data pins. Since the -WE line is also connected to the RAMs, this data will be written into RAM at the address on the address bus at that moment. For the first 32k U1 is selected and for the remaining 32k, U2 is selected. All 12 boards write at the same time but different data, depending on each board's note bus.

8.2.2 READ OPERATION

The -WE line will stay high for this operation, causing U4 to remain disabled, meaning that no data from the piano gets past U4. If data is read from a memory board, its read (S) line must be taken low. This will cause U3 and the RAM chips to enable, meaning that data from the preset address on the address bus will be transferred to the common system data bus and to the PC. Since each memory board is connected to a different read (S) line, data can be accessed from the 12 memory boards into the PC one by one for each address. This makes it possible to read 96 bits of data from the RAM for each address.

9. MASTER OSCILLATOR BOARD

Refer to drawing No. 06 Appendix A for the oscillator schematic diagram.

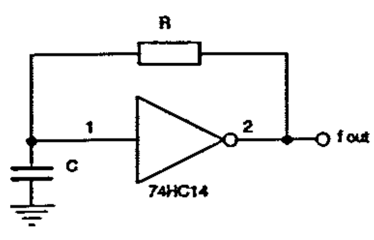
After some research, it was decided not to incorporate the oscillator into the mainboard design. This decision was made so that the oscillator can be replaced at a later stage with a micro processor controlled oscillator if required. However, the oscillator used in this design, has proved to be adequate as well as reliable as it does not drift more than about 5%.

9.1 FUNCTIONAL DESCRIPTION

The oscillator board generates and outputs a digital clock signal to the mainboard CLK input, which controls the speed at which the system records data from the piano. The speed can be selected as required by means of a rotary switch with six positions.

9.2 THEORY OF OPERATION

The oscillator is of the very straight forward CMOS inverter type.



9.3 CALCULATION OF COMPONENTS

From the above it can be seen that the frequency of oscillation is dependent on the R-C time constant. The input impedance of the inverter can be ignored as it is extremely high because it is of the CMOS type.

The frequency of oscillation is approximately given by:

$$f \approx \frac{1}{1.7*R*C}$$

For this application, the capacitor value of 1 μF was chosen after some trial and error.

The resistor value is given by:

$$R \approx \frac{1}{1.7*f*C}$$

With the above formula, the following values were obtained for R:

f(Hz)	R(calc)	R(use)	Preset
20	29.412k	22k	10k
30	19.608k	12k	10k
40	14.706k	10k	5k
50	11.765k	8.2k	5k
60	9.804k	6.8k	3k
70	8.403k	6.8k	3k

The preset pot values were chosen so that the frequency is adjustable around the required value. This was done to make it possible to calibrate the oscillator board precisely to the required frequencies.

9.4 HARDWARE DESCRIPTION

U1A is the oscillator inverter and C2 is the timing capacitor. SW1a selects the output frequency by switching in the different resistances which consist of a resistor and a preset pot.
It was found in previous applications where this type of oscillator has been used by the author, that the output of U1A is not a stable square wave if it is loaded directly. Therefore U1B was added to form a buffer. The output of U1B is a very stable and accurate square wave with a duty cycle of about 50 percent.

10. POWER SUPPLY

10.1 SPECIFICATIONS REQUIRED

To determine the specifications of the required power supply for the system, an attempt was made to calculate the power consumption of all the integrated circuits and resistors. This proved to be a too complex task, as the power consumption is dependent on the selected clock frequency and the number of notes pressed on the piano. It was therefore decided to use the practical approach of measuring the supply-current with a meter. The maximum supply current measured was with the system in the 'RECORD' mode. This current was about 5 ampere.
The supply for the system would therefore have to be capable of supplying this current plus another 20% for safety reasons. Therefore the power supply should be able to deliver 6 ampere to ensure reliable operation. The supply voltage required is 5 volt because all the logic used needs this voltage.

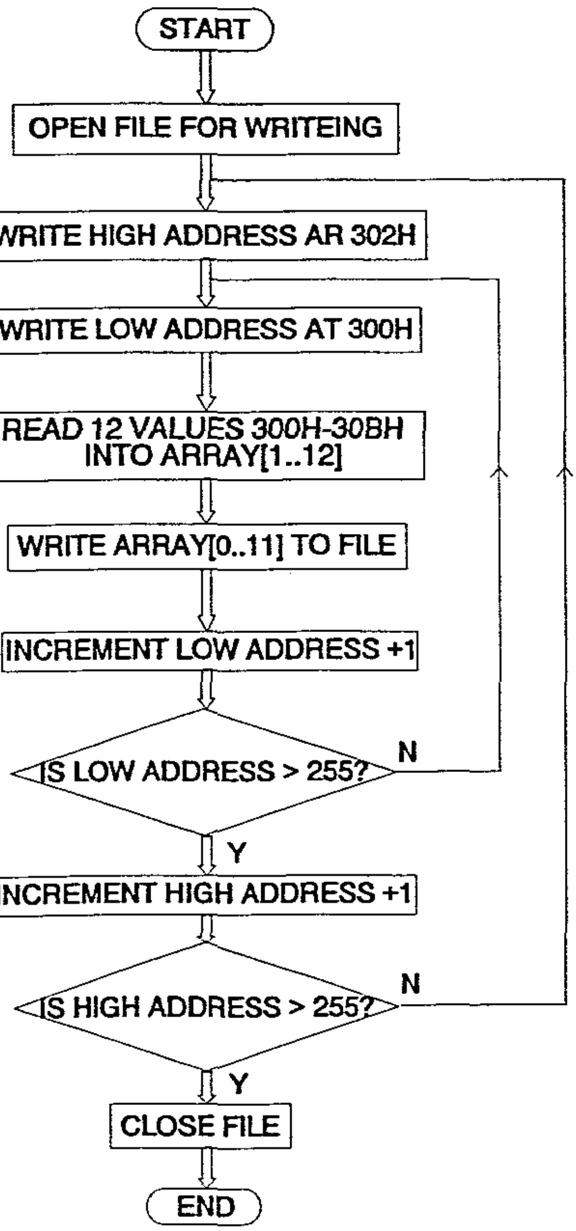
10.2 POWER SUPPLY CONSIDERATIONS

In order to meet the above specifications, a linear supply would have had to be designed and constructed.
However, after a cost estimation was done, it was decided that a ready made power supply could be obtained much cheaper than the designed one. Therefore, the supply finally used for this system is capable of delivering 20 ampere at 5 volt. The supply is of the switchmode type used for personal computers with a maximum rating of 200 watt.

11. SOFTWARE DEVELOPMENT

In order to read the recorded data from the memory of the system into the PC and store it onto disk, suitable software was developed.

Below, the basic flow diagram for the reading program is shown.



This program will count through the addresses, starting from 0, and write the high and low part to the mainboard. After every complete address has been written, 12 values are read from the mainboard memory. These 12 values contain one complete scan of the piano (96 bits altogether).

From the flowchart it can be seen that the address will keep increasing until the full 64k have been stored in the file. This would result in a file length of 64k x 12 = 768k, no matter how long the actual recording is.

To eliminate this unnecessary file size, a modification to the software was made which allows the user of the system to press the first and last note on the piano simultaneously after the recording is complete. The software tests for this and immediately stops with the reading process. This ensures that the file size is exactly the length of the recording.

Also, to speed up the file writing process, the program was adapted so that it will not write the array to disk each time. Instead, a two dimensional array is used, which is only written to the file after it contains 255 complete scans of the piano. This results in the same file format and size as before but the process becomes about five times faster. The software was written with TURBO PASCAL ver. 6 and a complete listing is supplied in Appendix B.

The software described here is a very basic version of the actual software used for the system as further elaboration of the software would not be in the interest of the author.

12. PROBLEMS ENCOUNTERED

When the prototype of the system was tested at first, it was found that it behaved intermittently. The cause of this was eventually found to be noise coming through the cable from the card inside the PC. This problem was eliminated finally after the address decoder card had been modified by adding a resistor and 2 diodes which disable the buffer on the card when it is not in use.

13. INSTALLATION

This Chapter describes the hardware and software installation of the piano-recorder system.

13.1 REQUIREMENTS

The complete piano-recorder system consists of the following:

(i) One upright piano.

(ii) Custom made switch-rail to fit into piano.

(iii) Piano-recorder control unit.

(iv) Piano-recorder address decoder card for PC.

(v) IBM or compatible personal computer with harddrive.

(vi) Connector cable witch 2 x DB25 connectors.

(vii) Mains power cable.

13.2 HARDWARE INSTALLATION

The following steps should be followed in order to install the piano-recorder system hardware properly:

(i) First, the switch-rail must be manufactured to fit into the particular piano used. The manufacturing of the switch-rail, its installation and its adjustment is a very complicated and delicate process which is best left to an experienced technologist. See Appendix C for the address of the author.

(ii) Place the piano-recorder control unit on top of the piano, preferably on a suitable piece of felt or matting, to prevent the surface of the piano from scratching.

(iii) Plug the four connectors marked A,B,C and D from the switch-rail into their appropriate sockets at the rear of the piano-recorder control unit.

(iv) Install the address decoder card into the PC and place the PC close to the piano-recorder control unit. A good place is next to the control unit on top of the piano. Care must be taken to prevent damage to the surface of the piano in any way.

(v) Connect the DB25 cable to the rear of the address decoder card in the PC and to the socket marked 'PC' on the control unit.

(vi) Connect the mains lead to the control unit and a suitable mains socket.

This completes the hardware installation process.

13.3 SOFTWARE INSTALLATION

The following steps should be followed in order to install the software of the piano-recorder system properly:

(i) Turn on the PC and wait for system boot.

(ii) Insert the piano-recorder disk into drive A and type A:INSTALL [Enter].

The software will then be installed onto the harddrive.

14. FUTURE DEVELOPMENTS

This chapter describes future developments around the piano-recorder system.

14.1 PERFORATING MACHINE

As the system described in this chapter was developed to assist the manufacturing process of pianola rolls, the next important development must be the machine that will punch out the rolls recorded. This machine should be controlled directly by the PC so that the rolls can be recorded and manufactured in one complete process. At the time of this writing, the basic layout of the machine has already been designed but a lot of fine details are still to be worked on, before the construction of a prototype.

14.2 ROLL DUPLICATING ATTACHMENT

Another important future development will be a device that can be connected to the piano-recorder control box instead of the switch-rail in order to duplicate existing pianola rolls. This device will consist of photo sensors which will 'read' the locations of the perforations in the roll to be duplicated.

14.3 SHEET MUSIC GENERATOR

If the piano-recorder is used in conjunction with a electronic metronome, it becomes possible to generate the sheet-music of the piece recorded. Experiments in this direction have already been made by the author but the software for this task is very complicated and at the time of this writing, experiments and software development continue. It must be realized that the piano-recorder has not been designed for this purpose and the process of sheet-music generation has already been accomplished by means of MIDI before.

14.3 REPRODUCING-PIANO RECORDER

It is planned that the second generation piano-recorder will be able to record not only which keys were pressed but also with what force they were pressed. This becomes necessary when Reproducing-piano rolls are to be recorded (see chapter 2), as these pianos are capable of reproducing a pianist's playing style ompletely. This system will however be very expensive and no experiments have been carried out in this direction at the time of this writing.

15. GLOSSARY OF TERMS

I/O	- Input/Output
LED	- Light-Emitting Diode
MIDI	- Musical Instruments Digital Interface
NC	- No Connection
PC	- Personal Computer
PCB	- Printed Circuit Board
PIANOLA	- Selfplaying Piano
RAM	- Random Access Memory

16. BIBLIOGRAPHY

Aeolian Company. 1927. **Duo-Art Reproducing Piano Service Manual.** The Aeolian Company, Aeolian Hall, New York.

Borland International. **Turbo Pascal 4.0 IBM Version.** Borland International, Inc.

Bowers, Q. David. 1972. **Encyclopedia of Automatic Musical Instruments.** New York, Vestal Press.

Cockayne, Eric V. **The Fairground Organ.** Newton Abbot, David & Charles.

Cypress Semiconductor Corporation. March 1991. **BiCMOS/CMOS Databook.** San Jose CA.

Floyd, T. 1986. **Digital Fundamentals 3rd Edition.** Columbus, Ohio 43216. Charles E. Merrill Publishing Co.

Intel Corporation. 1991. **Memory Products.** Santa Clara, US.

Microsoft Corporation. 1987. **MS-DOS Version 3.3 User's Guide.** United States.

Mohr, H. **Die MIDI Schnittstelle - Möglichkeiten und Grenzen moderner Technologien.** Das Mechanische Musikinstrument 1991(54),26. Gesellschaft für selbstspielende Musikinstrumente e.V.

Mohr, H. **Ein Wettstreit neuer Selbstspielklaviere.** Das Mechanische Musikinstrument 1992(55),33. Gesellschaft für selbstspielende Musikinstrumente e.V.

Music Box Society International. 1974. **Silver Anniversary Collection.** Musical Box Society International, New Jersey.

National Semiconductors Corporation. 1989. **CMOS Data Book.** Santa Clara.

Ord-Hume, Arthur W.J.G. **Player Piano.** London, George Allen and Unwin Ltd.

Roehl, Harvey N. 1973. **Player Piano Treasury, 2nd Edition.** New York, Vestal Press.

RS Export Centre. July - October 1990. **RS Components Catalogue International Edition.** Corby Northants England.

Texas Instruments. **The TTL Data Book 4th Edition 1980.** Texas Instuments.

Uchdorf, Hans-Jürgen. 1985. **Klavier-Praktisches Handbuch für Klavierbauer und Klavierspieler.** Germany, Heinrichhofen's Verlag, Wilhelmshaven.

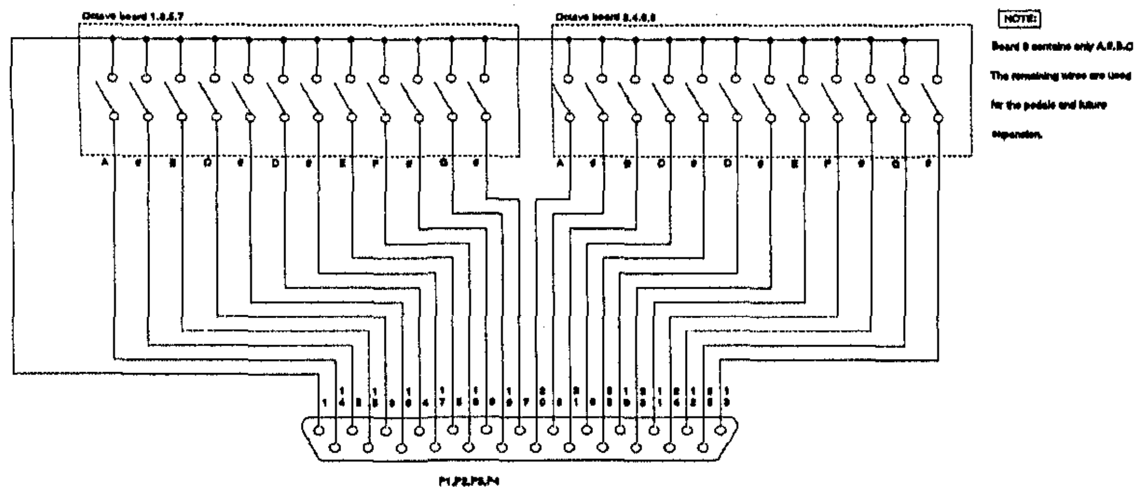
Union Europäischer Pianomacher-Fachverbände. 1/1988. **Europiano 1988(1), 25.**

APPENDIX A

SCHEMATIC DIAGRAMS OF THE PIANO-RECORDER SYSTEM

Drawing No 01

A-2



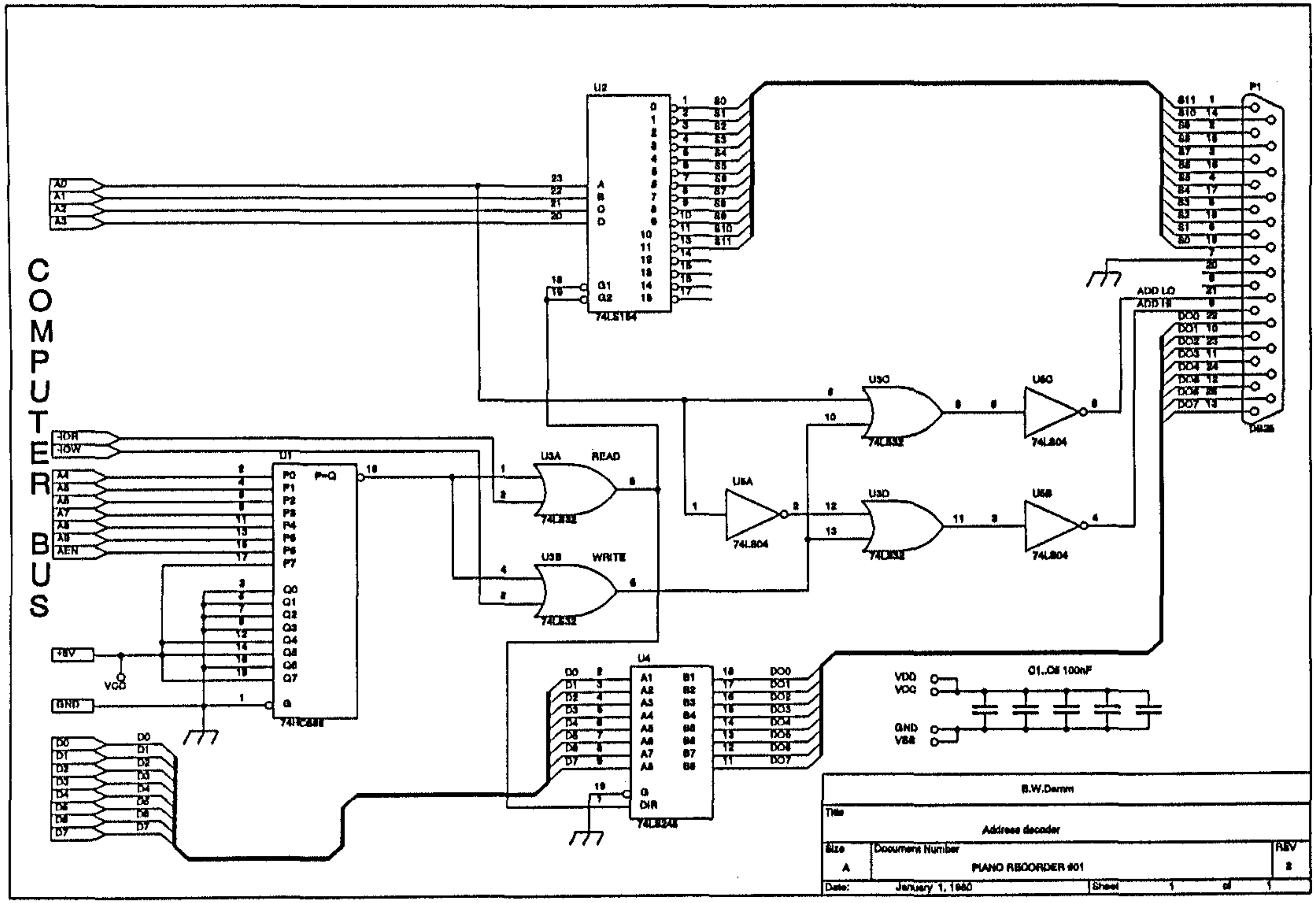
The aboce diagram shows two of the eight boards

contained in the switch-rail.

B.W.Damm		
Title: SWITCH-RAIL LAYOUT		
Size: A	Document Number: PIANO-RECORDER SW	REV: 0
Date: February 23	Sheet 1 of 1	

SWITCH-RAIL

Drawing No 02

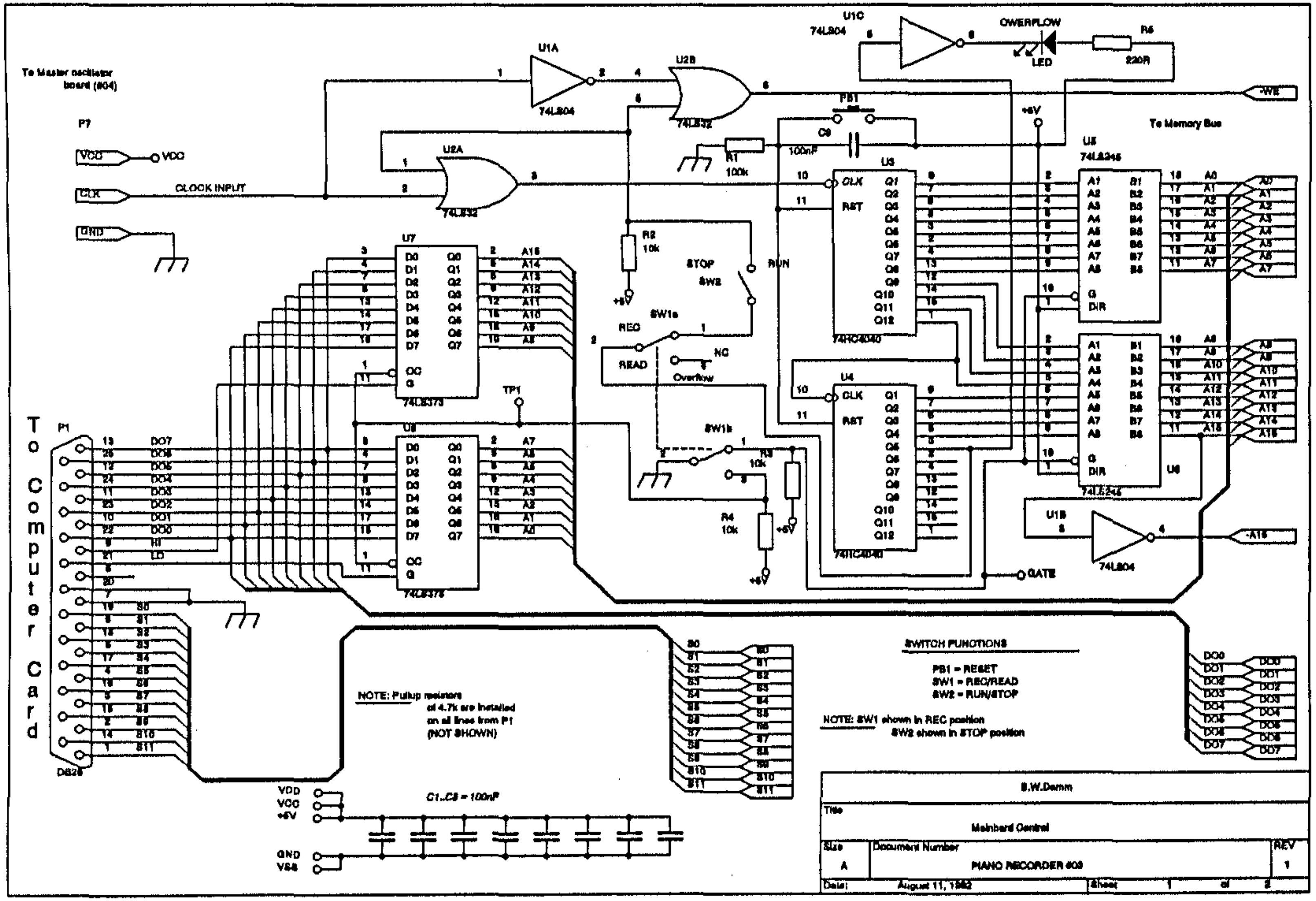


A-3

ADDRESS DECODER CARD

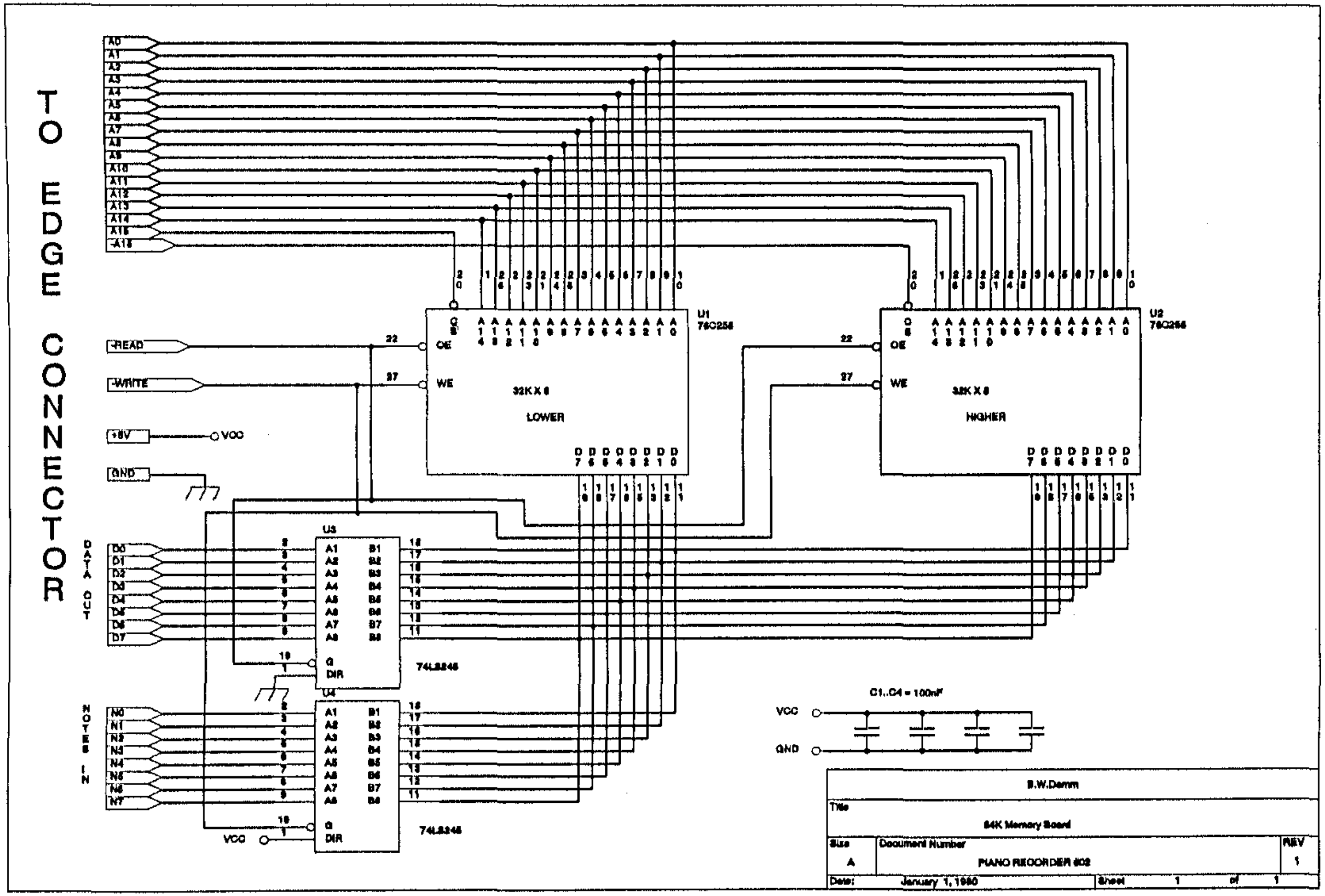
Drawing No 03

A-4



MAINBOARD

Drawing No 04

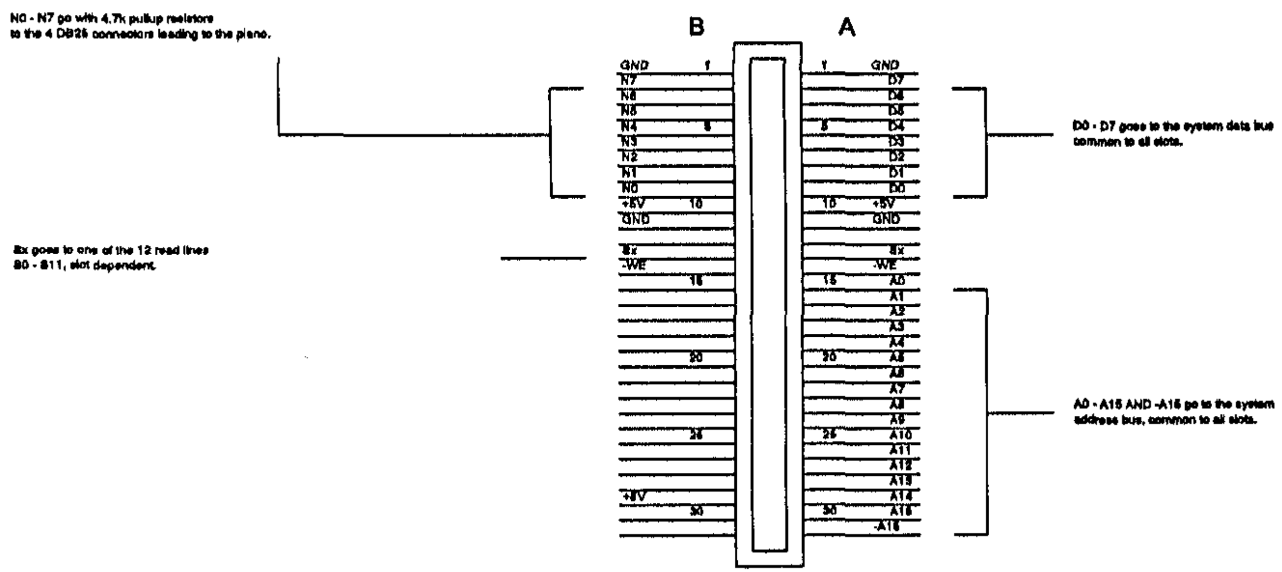


A-5

MEMORY BOARDS

Drawing No 05

A-6



PINOUT DIAGRAM FOR MEMORY BOARD SLOTS

NOTE: There are 12 of these slots on the mainboard.
Pins not named, are not connected.

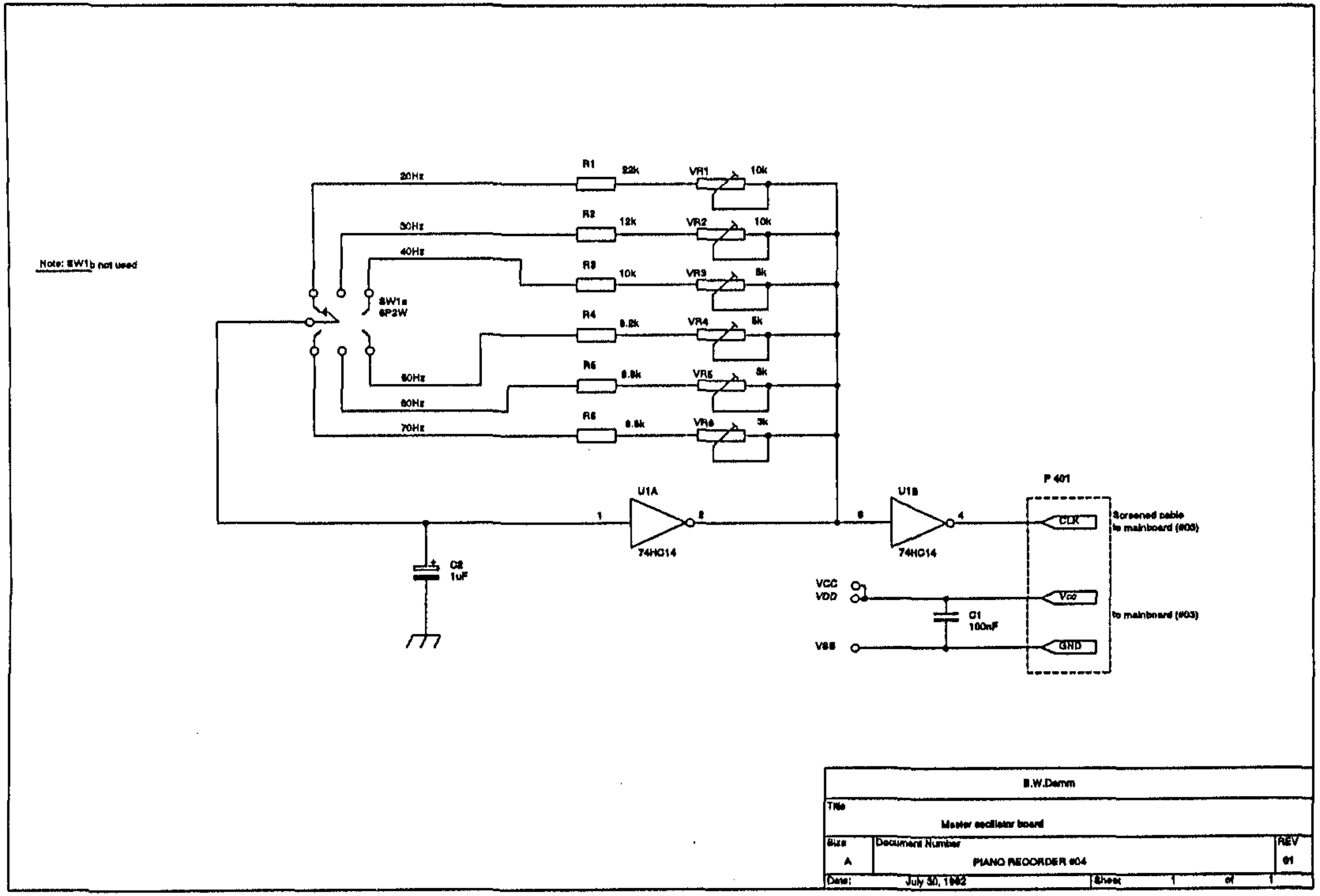
S.W.Demm		
Title: Memory board slot		
Size: A	Document Number: PIANO RECORDER #01-1	REV: [illegible]
Date: March	Sheet 1 of 1	

SLOT PINOUT SCHEMATIC

Drawing No 06

A-7

MASTER OSCILLATOR



APPENDIX B

LISTING OF SOFTWARE

The software listed in this appendix is a very basic version of the actual software used for the system. It is included in this thesis only for the purpose of demonstrating the principle of how to access the piano-recorder with a PC.

The listed program has been written for Turbo Pascal Version 6.

```
Program Ramread;     {PIANO-RECORDER #1}

              {(C) by B.W.Damm 1992}
{This Program Reads the data from the piano-recorder board
and stores it on disk in the following FIle Format:
Arrays[1..12] = 12 bytes of 8 notes each as read from the 12
boards on the piano-recorder mainboard.
The user will be prompted for the destination filename.}

{******** Added function: ********}
{If piano note #1 and note #88 are pressed simultaneously then
this is interpreted by this program as th end of a song and the
data transfer is stopped and the file closed.}

{For a 85 note piano, this testing loop will have to be modified}


Uses Crt;
                            {Notes,Linecounter}      {Used for speed only}
Type AR = Record scan : Array[1..12,0..255] of byte  {#of notes from board}
          end;{type}


Var
 x,lo,high,high1,lo1,inread : byte;
                      range : integer;
                        bin : array[0..7] of byte;
                       Dest : File of AR; {Output file format}
                     Output : AR;          {Scan format}
                    Filelen : Integer;     {File counter}


Procedure FILEOPEN;  {Opens the Destination file as specified}
                     {by user}

   Var Into : String[50];  {Filename}

   Begin
    Clrscr;
    FILELEN:=0; {Counter for output filelength}
    Gotoxy(10,8);
    Writeln('This program Reads and Saves the memory from the mainboard');
    Gotoxy(25,9);
    Writeln('(C) 14/11/92 by: B.W.Damm');
    Gotoxy(20,12);
    Writeln('PLEASE ENTER DESTINATION FILENAME');
    Gotoxy(29,13);
    Fillchar(Into,50,' '); {Clear Array}
    Readln(INTO);          {Get filename}

      Assign(DEST,INTO);   {Open file for rewriting or creating}
      Rewrite(DEST);
   end;{FILEOPEN}
```

```
Procedure ENDCODE;  {called by READIN}
                    {Checks if note 1 and 88 were pressed simultaneously}

Begin                          {Active high data logic}
  If (Output.scan[1,Lo] = 1)  and (Output.scan[11,Lo] = 128) then
        Begin
          Write(dest,output);  {Updates file + 256 records}
            Filelen:= Filelen+1;
              Clrscr;
                Sound(1440);   {Beep if EOS found}
                 Delay(100);
                Nosound;
               Gotoxy(20,10);
              Writeln('End of Song found !  ',Filelen:5,'  Lines saved');
             Close(Dest);
            Writeln('                          Press Enter key to Exit');
           Readln;
        Halt;                  {Program terminates here if EOS found}
      end; {If}
    end;{proc}


Procedure READIN;  {Reads the 12 data values at one address}
  Begin
       {  Description }
    {Hex    Board   Notes}
    {300 =  1       1-8}
    {301 =  2       9-16}
    {302 =  3       17-24}
    {303 =  4       25-32}
    {304 =  5       33-40}
    {305 =  6       41-48}
    {306 =  7       49-56}
    {307 =  8       57-64}
    {308 =  9       65-72}
    {309 =  10      73-80}
    {30A =  11      81-88}
    {30B =  12      89-96}

      {Read 12 Board values and store in file array in special order}
           Output.scan[1,LO]:=port[$302];
           Output.scan[2,LO]:=port[$301];
           Output.scan[3,LO]:=port[$300];
           Output.scan[4,LO]:=port[$305];
           Output.scan[5,LO]:=port[$304];
           Output.scan[6,LO]:=port[$303];
           Output.scan[7,LO]:=port[$308];
           Output.scan[8,LO]:=port[$307];
           Output.scan[9,LO]:=port[$306];
           Output.scan[10,LO]:=port[$30B];
           Output.scan[11,LO]:=port[$30A];
           Output.scan[12,LO]:=port[$309];
```

```
        Gotoxy(26,15);
          Write(Filelen:5);     {Display lines converted}
           ENDCODE;             {Check if #1 and # 88 pressed }
         Filelen:= Filelen+1;   {File line Counter is updated}
     end;{proc}



BEGIN  {Main program}
    Fileopen;                               {Open the destination file}
    Clrscr;
    Gotoxy(10,10);
     Writeln('Saving, Please Wait...');
      Gotoxy(10,15);
       Writeln('Now Doing Line: ');
       for high:= 0 to 255 do               {Outer loop high addrss cntr}
           begin
             port[$301]:=high;              {Output high address}
               for lo:= 0 to 255 do         {Inner loop low adress}
                 begin
                 if keypressed then begin Close(dest); halt; end;

                   port[$300]:=lo;          {Output low adress}
                 Readin;                 {Read all values at that address}
                                         {Into the output.scan array}
                end; {Inner loop}
              write(dest,output);        {Updates file + 256 records}
            end;        {Outer loop}
     close(dest);       {Close file}
  writeln(char(7));     {Beep}

end. {Program}
```

APPENDIX C

ADDRESS OF AUTHOR AT TIME OF WRITING

Any correspondence with the author on the subject discussed in this thesis should be done to the following address:

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9 Sonneblom Street
Bellville,7530
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