A Digital Flute
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Introduction

This paper describes a microprocessor-based digital flute instrument with a novel keying arrangement. The keys are arranged for easy translation from treble clef notation to finger placement. Alternate keying patterns to suit the performer can be realized through simple adjustments in the keying circuits and/or software.

Traditionally, most performance-oriented computer music instruments have used the organ (piano) keyboard as the primary interface between musician and machine. Thus, musicians trained on instruments other than the keyboard have had a limited choice for exploring composition and performance using music synthesis techniques.

In order to alter this situation, we have designed and built an electronic instrument that incorporates a musician/machine interface device other than the piano keyboard. The digital flute, as we call it, serves two primary purposes. First, it expands the field of music synthesis to those musicians not familiar with the piano keyboard. Second, due to the unique keying arrangement, the flute could be used as a learning instrument for music students.

We will describe the external operation characteristics of the flute, as well as the internal components that make it work. These include the microcomputer hardware, an analog circuit, and the software used by the processor.

Playing the Flute

The prototype instrument externally consists of ten switches, a control potentionmeter, and a microphone mounted on a tubular clear plastic body (Fig. 1). The musician holds the flute in the same way that a traditional flute is held. The flute generates a single tone, with the pitch dependent on a combination of closed switches. The attack, sustain, and decay of the tone are controlled by sound produced by the performer blowing across a small condenser microphone located at one end of the flute. Playing the flute is as simple as blowing across the top of an empty bottle. In addition, some of the blowing sound is mixed with the signal to produce a "breathy" tone resembling the sound of a conventional flute. The breathy portion of the signal can be adjusted by the control potentiometer.

Figure 2 shows the novel fingering scheme used by the flute. Each key is logically related to a line on the musical staff. To play a note located on a line, the musician must simply depress the key corresponding to that line. To play a note located between two lines, the two keys corresponding to the lines between which the note is situated must be depressed simultaneously. Any note can be made sharp or flat by simply depressing either the sharp key or the flat key in conjunction with the other keys.

Thus, a maximum of three keys can be depressed at any time. No sound is produced for an invalid fingering arrangement. The range of playable notes spans two octaves: from middle C to the C-sharp two octaves above middle C.

A person requires little previous knowledge of music to play the flute. All that the player must do is relate the lines on the musical staff to the switches on the flute and concentrate on the timing. Once the simple rules for playing notes are understood, a beginner can easily play simple tunes on the flute.

Internal Circuitry

A block diagram of the flute's circuitry is shown in Fig. 3. The ten switches (keys) are connected directly to a matrix of diodes. This matrix converts

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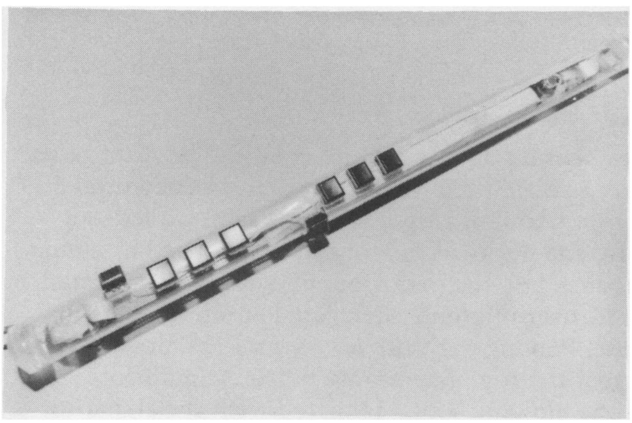


Fig. 1. The digital flute developed at the University of Manitoba, Winnipeg, Canada.

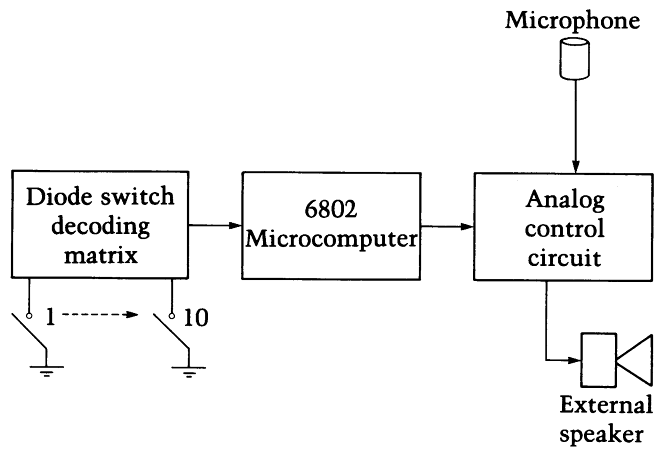


Fig. 3. System block diagram.

Fig. 2

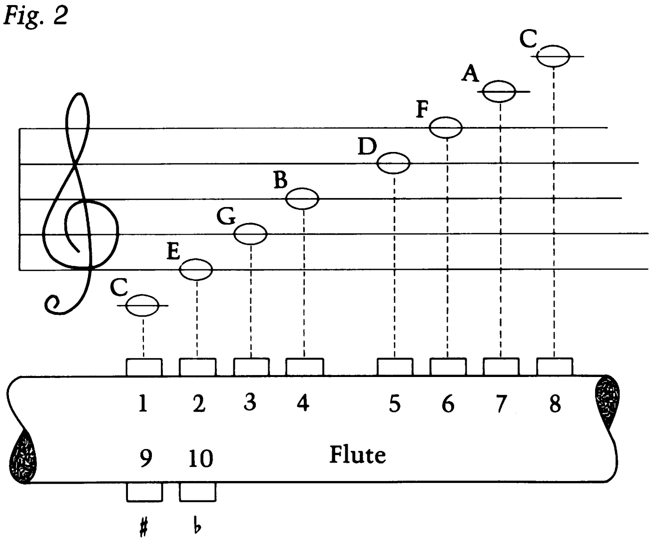


Fig. 2. Fingering scheme for the digital flute.

Fig. 4

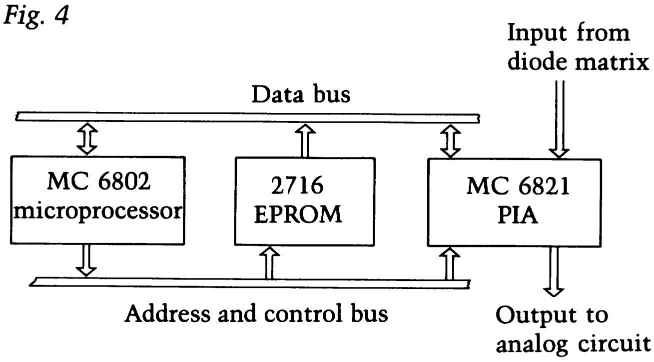


Fig. 4. Microcomputer block diagram.

each valid combination of depressed switches into a unique binary identification (ID) number. A Motorola 6802 microprocessor is used in the microcomputer section. The 6802-based microcomputer converts the ID number to a square wave of the correct frequency. The square wave's amplitude is modulated by the microphone output by means of the analog circuit. The final signal is then passed to an external speaker/amplifier unit. The entire circuit is housed inside the flute body. Four wires connect the flute to the amplifier, and an external DC power supply.

Microcomputer Circuit

In its simplest form, a computer consists of a processing unit, a memory device, and an input/output (I/O) device. Accordingly, the heart of the flute is a 6802-based microcomputer, as shown in Fig. 4.

The MC 6821 peripheral interface adapter, or PIA, is the I/O device. It provides an interface between the processor and both the diode matrix and the analog circuit. The microprocessor primarily monitors the diode matrix, generates ID numbers, and produces a single square-wave voltage output.

The 2716 erasable, programmable read-only memory (EPROM) contains the machine language program for the 6802 and a table of valid ID numbers.

Fig. 5. *Software flowchart.*

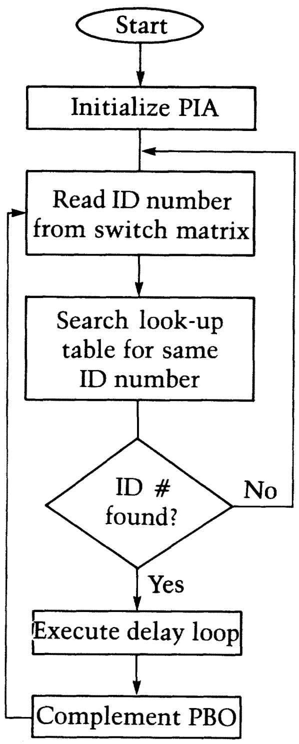
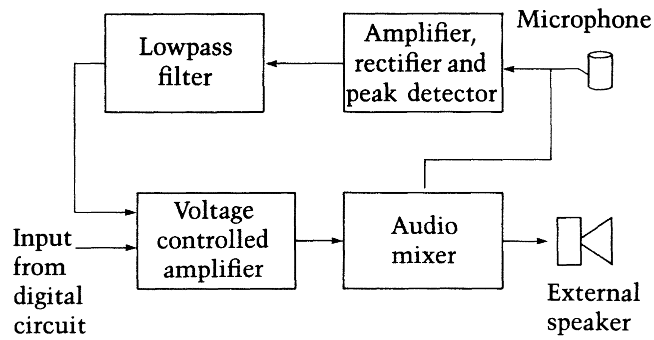


Fig. 6. *Analog control circuit block diagram.*



System Software

Figure 5 shows a simplified software flowchart. The microprocessor begins executing the program when power is applied to the flute. This is accomplished by a simple power-up reset circuit. The PIA must also be initialized to behave as both an input and an output device prior to the first input (read) operation.

The program runs continuously in tight loop mode and scans the switches for closures via the PIA. A search in a lookup table consisting of only valid ID numbers and timing data is then performed. Therefore, if an invalid ID number has been read, the read and search steps are repeated until a correct fingering arrangement produces a valid ID number.

The timing data is extracted from the lookup table, and is used to specify the number of times that a software delay loop should be executed. The timing loop is set up in such a way that once through the entire program takes exactly half of the time period of the tone being produced. Each time through the entire program, one line of the PIA output is complemented. The string of logic 1s and 0s thus produced forms a square-wave voltage of the required frequency. The square wave is also the input to the analog control circuit.

Analog Control Circuit

The analog circuit performs two major functions. First, the AC microphone output voltage is converted to a DC control voltage. The magnitude of this voltage is proportional to the microphone output, which in turn is proportional to the musician's blowing strength. Second, the control voltage is used to modulate the amplitude of the tone generated by the flute. The overall objective of the analog circuit is to make the loudness of the tone proportional to the blowing strength.

Figure 6 shows a block diagram of the final analog circuit. The combination amplifier, rectifier, and peak-detector converts the AC signal to a steady DC voltage. However, the DC voltage thus produced contains a high-frequency noise component. The noise is subsequently removed by the lowpass filter, which was designed from a text on operational amplifiers (Coughlin and Driscoll 1977).

The second function is performed by a voltage-controlled amplifier (VCA). This amplifier has a gain that is proportional to the DC control voltage. Thus, the larger the control voltage, the louder the tone sounds. The VCA design is based on a circuit

Fig. 7. M. Borys playing the digital flute.

developed in the RCA Laboratories (Wittlinger 1971). The audio mixer adds the microphone output to the signal output to produce a "breathy" sound. The total signal is fed to an external unit foı amplification and sound generation.

Conclusions

We have successfully designed a digital flutelike instrument with a simplified fingering arrangement. A photograph of the instrument being played is shown in Fig. 7. The fingering scheme can easily be altered by either changing the diode matrix or by rearranging the order of the lookup table of ID numbers. A different range of notes can also be realized by altering the timing information stored in the lookup table. Thus the flute is a flexible interface device.

The software developed for this project is one of the flute's most significant features. It provides highly accurate notes (within 1 cent of the desired frequency) in a speed sufficient for real-time operation. The analog control circuit also provides realistic-sounding control over the loudness of the note.

The flute can also serve as a musical teaching tool. The straightforward fingering scheme implies that extensive musical knowledge is not required to play the flute. The microphone is easy to blow across, thus decreasing the importance of embouchure, which is difficult to learn for many woodwind instruments.

Many other applications can be found for the flute. A useful application would be to use the flute as the musician/machine interface device to a digital synthesizer.

Acknowledgments

The authors would like to acknowledge the work of Darryl Honer and Darren Gates who built the first version of the microprocessor-based flute as their B.S. thesis (Gates and Honer 1983). The switch-decoding matrix, the digital circuit, and the software used in the present version of the flute were developed by these two gentlemen.

Also, special thanks are extended to Ken Beigun for his help in the construction of the flute, and to all the other technologists at the University of Manitoba who contributed to this project.

The authors would also like to thank the Ontario Science Centre for using the digital flute in an exhibit entitled "The Artist as a Young Machine" during the summer show of 1984.

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