TINKER'S TOYS

Lessons from Bank Street: Hardware

by Robert Tinker

We have recently completed the development of the *Bank Street Laboratory*, a set of hardware and software tools that allows kids to do temperature, light, and sound measurements. Some technical aspects of the development effort may be of interest to readers who are implementing their own Microcomputer-Based Laboratory.

The Bank Street Laboratory consists of a board that plugs into the Apple, cabling, software, and six probes of which any two can be used simultaneously. The system is for students as low as 4th grade so it must be robust, relatively foolproof, and inexpensive. You might think that the software should be relatively simple for such an unsophisticated audience, but in fact, the opposite is true. The software must make a very complex tool easy to use.

The software permits a wide variety of temperature, light, and sound measurements. The most spectacular software supports an oscilloscope-type display of sound and the ability to capture a second's worth of sound, play it back, examine it in detail, and frequency analyze it. We will say more about the software in next issue's *Toys*.

The Analog-to-Digital Converter

We selected the Hitachi HD46508PA ADC as the workhorse of the system. The HD46508PA performs 10-bit conversions in 100 microseconds and costs only $6.00. It has 16 analog inputs, interfaces directly to the Apple's I/O bus, and has all kinds of advanced features that we didn't even bother to utilize. Figure 1 shows how to connect the HD46508PA to the Apple bus with no additional components.

The Multiplier Chip

One of the project design goals was to be able to do real-time Fourier analysis. The fastest 256 Point Fourier Transform requires five seconds on an ordinary Apple. We were able to cut this down to 0.5 seconds with a hardware-multiplication chip: the 6203 from Oki Data Systems. Like the Hitachi ADC, the 6203 is new, inexpensive ($7.00 each), and attaches to the Apple I/O bus easily. Figure 2 shows how this can be done with one external gate.

The Oki 6203 is an 8-bit unsigned multiplier and divider. It can produce a 16-bit product in just a little more than the time required to load the operands and read the results using 6502 machine-language. If you do the sequence right, one No-Op instruction wastes just the time required for the multiplier chip to develop a 16-bit product or quotient. Listing 1 gives a short machine-language test program for the 6203 plugged into slot 2 of the Apple.

Software Probe Identification

One of our ideas to make the system as user-friendly as possible was to have it detect what probes were currently connected to each of its two inputs. Each probe incorporates an identification resistor that is measured by the board. We even had different identification resistors for the two color-coded temperature sensors supplied as part of the package. This allows the red and blue temperature sensors to draw appropriately calibrated red and blue lines on the graph, regardless of how they are connected.

This idea turned out to be tremendously important and useful at many points in the system. Messages can be flashed to connect a particular kind of probe or output device. A message to attach the speaker or the light detector flashes on the screen until the appropriate device is attached. Sometimes the system does not care what is attached but reports back to the user what it senses. This provides a very nice feedback loop.

The Modular Connectors

In an effort to keep the probe cost as low as possible, we decide to use the four-wire modular connector system developed for telephones. Both the wire and

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the connectors are extremely inexpensive, readily available, and quite reliable. They lack the shielding usually used in instrumentation, but we made sure that the sensors were relatively low impedance so that shielding was not important.

The four conductors are just barely enough for a universal input and output device connection. They connect: ground, analog input, analog output, and the ungrounded side of the identification resistor.

Input Switching

Each kind of probe used (temperature, light, and sound) requires its own input-signal processing circuit. The light sensor is a cadmium sulfide cell that requires only a pull-up resistor to generate a voltage appropriate for the ADC. The temperature sensor is a simple forward-biased diode, which requires a biasing circuit and a high-gain amplifier with variable offset. The sound detector is an electret microphone and requires a pull-up resistor and an AC-coupled amplifier with variable gain. We intend to develop conditioning circuitry for other transducers.

These circuits are connected to the input sockets via 4066 CMOS analog switches. One possible configuration is shown in Figure 3. Two different inputs switch into one of seven possible input processing circuits. The output of each of these seven circuits is connected to one of the ADC's analog inputs.

The disadvantage of this scheme turns up when you want to measure the same kind of probe quickly on two different inputs. For instance, we wanted to do a speed of sound experiment using two microphones. The input circuit can switch one microphone and then the other into the amplifier, but because there is a DC offset in the circuit, it takes a considerable length of time for the input to settle after switching. If this were a problem, one could supply separate identical amplifier circuits.

Temperature Measurements

We chose to use the common 1N914 diode as the temperature sensor. It is not widely known that the forward-biased voltage of any diode varies approximately linearly with temperature at 2.2 millivolts per degree Celsius. This requires a simple operational amplifier circuit with a DC offset. Since the board includes a digital-to-analog converter, we use the output of that to supply the DC offset to an amplifier with a gain of 15.

The Microphone

We chose an electret microphone avail-

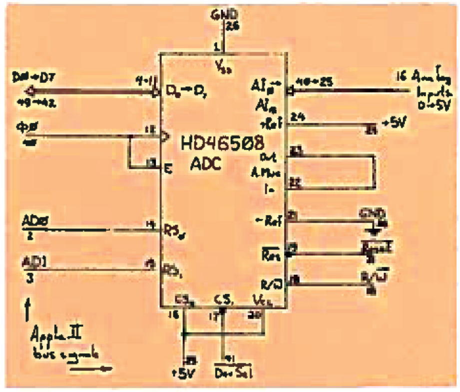

Figure 1

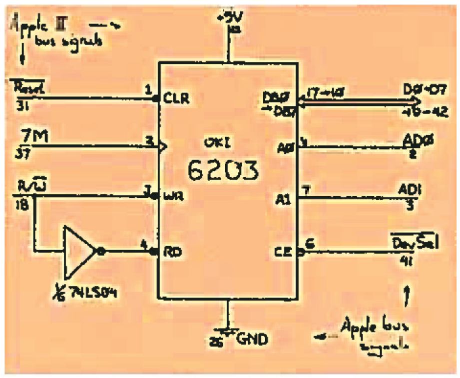

Figure 2

able from Radio Shack for about a dollar and from wholesale distributors for considerably less. Pressure waves vibrate a metalized film in the microphone next to a metal plate. The microphone is actually a capacitor with a built-in FET transistor that amplifies the signal and converts it into what appears to be a variable resistance. The electret microphone appears as a two-terminal device requiring a pull-up resistor of typically 5 KΩ and AC coupling to a current-to-voltage amplifier with a typical gain resistance of 10^5 to 10^6. See Figure 4.

Gain Switching

Both light and sound inputs have an extremely wide dynamic range. We chose to accommodate this wide range by using gain switching, using analog switches to alter the gain of the input circuit. In the case of the photoconductive cell, it simply meant switching out the pull-up resistor with one of a smaller value. In the case of the audio amplifier, it meant putting a smaller resistance value in the feedback loop of the amplifier. Both of these circuit ideas are shown in Figure 5.

In next issue's *Tinker's Toys* we will share some elegant programming tricks for real-time graphics and more.

(Continued on page 18)

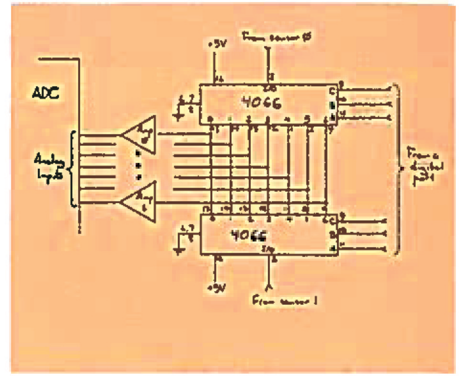

Figure 3

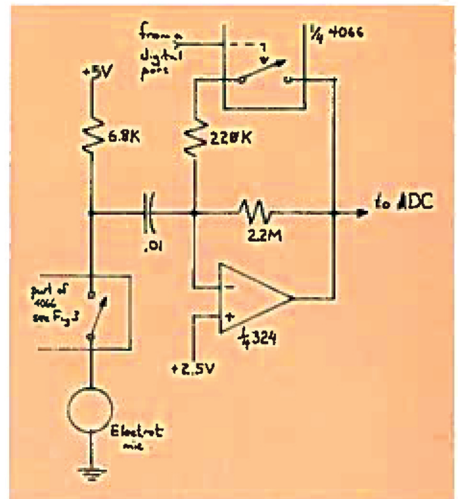

Figure 4

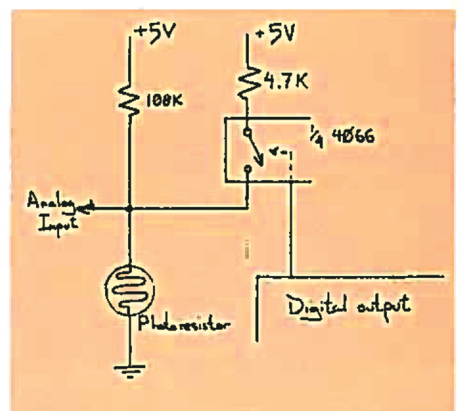

Figure 5

IDEA EXCHANGE

The Idea Exchange is designed to be a two-way street, where we share some of our ideas and ask for feedback. This two-way exchange is particularly useful to us now. We need to find out how well MBL works for different topics, especially in the classroom. We also hope that this exchange will inspire readers to come up with new experiments, new probes, and new software. If you do, please tell us.

Probeless MBL

Human perception, motor control, and response are but some of the areas of experiment suitable for probeless MBL. The simple response experiments presented in "Probing MBL" are typical. You can perform tachistoscope experiments using the computer's screen to flash messages and asking the students to replicate or identify what they saw. An Apple can present any of its three screens, fully formed, for any multiple of 30 ms. Thus a large range of classic perception experiments that measure short-term and long-term memory and investigate the role of meaning in memory could be easily implemented.

Another kind of non-probe input is provided by the standard game paddles and tablets. A game paddle is a rotation transducer, or pot. It could be used as the pivot for a physical pendulum or outfitted with an arm to measure mechanical displacement.

Probes and Processing

It may seem obvious at this point, but keep the computer's computational ability in mind when coming up with applications for probes. Many phenomena that used to require special transducers may be measured easily if an *indirect* approach is taken. Thus you can calculate heart rate, speed of chemical reaction, speed and position of an object, and other phenomena from a light measurement. This processing also lessens the need for a sensor to behave linearly, and makes calibration a breeze. Long-term stability doesn't matter as long as a reference is available.

Probes

Temperature, light, and resistance are the easiest parameters to read through game-paddle electronics. They may not seem like the basis for many experiments but, given the computer's processing ability, prove incredibly versatile. Almost all of the experiments listed in the *Software Review* rely on them.

Light and temperature can cause a variation in the resistance that can be measured by game-paddle input. Other sensors are not so convenient, but we have built a voltage-to-game-paddle converter using an opto-isolator and an op-amp that allows pH and mV to be measured with the game-paddle input.

The cost of electrodes is an impediment to many chemistry applications. We need ideas for inexpensive specific ion or oxygen electrodes. What electro-chemical experiments are simple and revealing?

Sound is another exciting area. The Apple's game-paddle input is good for up to 1kHz; a $6.00 ADC chip like the Hitachi converts in 80-100 µS. Kids seem to find sound fascinating: they spend hours using the tools for recording, examining, and replaying sounds provided by the *Bank Street Laboratory*. The potential of Fourier analysis and synthesis has not even been scratched. We imagine that kids might want to bring in their pop records and try to analyze and reproduce some of the electronic sounds that they hear. Fourier analysis can also be used for vibration and resonance studies.

There are many other neat probes that are just waiting for the right application. Strain gauges can be used in many ways to measure force. A phonograph cartridge can be driven by an oscillator and another can detect the resulting vibration in some solid body. A piezo-electric crystal is good for creating and detecting high frequency and ultrasonic sounds. Could we do some creative form of ultrasonic imaging or measure speeds of liquids and objects with ultrasonic Dopler shifting? There are some solid state pressure transducers that could be used to measure atmospheric pressure and air and water flow rates. Magneto-restrictive probes can measure large magnetic fields; Hall-effect probes can measure small ones. Solid-state detectors can measure ionizing radiation. It would be wonderful to measure random radioactive decays, both to investigate environmental hazards, and to study statistical processes. Are there inexpensive detectors suitable for educational use?

Thermocouples are good for measuring temperatures and temperature differences; a thermoelectric cooler can be used to measure heat flow; wire can be used to measure high temperature. Wouldn't the investigation of a flame be a nice interdisciplinary chemistry and physics study? Smoke detectors can be used for detecting ionized particles. Flammable gas detectors can be used to detect low concentrations of a number of different compounds. The auto-focus electronics in Polaroid cameras can be used to measure distances. A pair of conducting plates, acting as a capacitor, can be used to measure the depth of dielectric liquids, or to measure the separation of the plates. A pair of electrodes can be used to measure the fluid conductivity, and hence, measure ion concentrations. A small DC motor makes an excellent tachometer.

There is a lot of electrical activity in the human body that would be nice to pick up. The simplest is the heart's electrocardiogram (ECG). With a number of electrodes perhaps we could isolate individual muscle movements in the heart. Next easiest is an electromylogram (EMG), which measures muscle activity. It would be wonderful to correlate the force produced by a muscle, measured with a force gauge, with the strength of the EMG discharges. An order of magnitude more difficult, are the electroencephalogram (EEG) signals produced by the brain. Frequency analysis would show alpha, beta, and gamma waves used in feedback training. How difficult is it to do correlation analyses that give some sense of where the EEG waves are originating in the brain, or to do evoked potential measurements? Other ideas? Let us know.

Tinker's Toys . . . Listing 1

```
0000        ************************
0000        *                      *
0000        *      OKI 6203        *
0000        *   8-bit multiply     *
0000        *    16/8 divide       *
0000        *                      *
0000        ************************
0000
0000
0020        SLOT        EQU  $20            slot number * $10
0000
C0A0        BASEADR     EQU      $C090 + SLOT
0000
0000        ; OKI 6203 chip registers
0000
C0A0        OKI X     EQU     BASEADR + 0
C0A1        OKI Y     EQU     BASEADR + 1
C0A2        OKI Z     EQU     BASEADR + 2
C0A3        OKI COMM     EQU     BASEADR + 3
0000
```

```
---- NEXT OBJECT FILE NAME IS OKI.OBJ

0300                            ORG   $300
0300
0300                MULT        EQU*
0300
0300                 Call with bytes to multiply in A and Y
0300                 Returns with two byte value in A Y (high-low)
0300
0300 8C A0 C0                   STY   OKI X
0303 8D A2 C0                   STA   OKI Z
0306 A9 02                      LDA   #2          ; multiply command
0308 8D A3 C0                   STA   OKI COMM
030B EA                         NOP
030C AD A1 C0                   LDA   OKI Y       high byte
030F AC A2 C0                   LDY   OKI Z       low byte
0312 60                         RTS
0313
0313
0313                DIVIDE EQU   *
0313
0313                 Call with 2 byte dividend in A and Y (high-low),
0313                 divisor in X.
0313                 Returns quotient in A and remainder in Y.
0313
0313 8E A0 C0                   STX   OKI X
0316 8D A1 C0                   STA   OKI Y
0319 8C A2 C0                   STY   OKI Z
031C A9 01                      LDA   #1          divide command
031E 8D A3 C0                   STA   OKI COMM
0321 EA                         NOP
0322 AD A2 C0                   LDA OKI Z
0325 AC A1 C0                   LDY   OKI.Y
0328 60                         RTS
0329
```

Probing MBL . . . Listing 5

```
100   REM PEND
110   REM NOV 20, 1984
120   REM GRAPHS A PENDULUM
130   REM ON AN APPLE II
140   REM
150   REM USE GAME PADDLE 0 OR A POT
      CONNECTED TO PDL0
160   REM AS A PIVOT FOR A RIGID PENDULUM
170   REM
180   REM
190   TEXT   HOME
200   VTAB 8  PRINT "SET PENDULUM AT REST "
210   INPUT "PRINT RETURN WHEN DONE  ",A$
220   X0 = PDL (0)
230   HOME
240   VTAB 8  PRINT "PULL PENDULUM TO MAX DISPLACEMENT "
250   INPUT "PRESS RETURN WHEN DONE. ",A$
260   X1 = PDL (0)
270   A = 80 / (X0 - X1)
280   B = - A * X1
290   HOME   VTAB 22  INPUT "PLOT FOR HOW MANY SEC? ",T
300   HGR   HCOLOR= 1
310   HPLOT 0 80 TO 279 80
320   HCOLOR= 3
330   FOR X = 0 TO 279 STEP 6.09 / T
340   Y = A * PDL (0) + B
350   IF Y > 159 THEN Y = 159
360   IF Y < 0 THEN Y = 0
370   IF X = 0 THEN HPLOT X Y
380   HPLOT TO X,Y
390   NEXT X
400   GOTO 290
```

A Call For Participation

WE NEED YOUR INVOLVEMENT:

- Show us your interest in MBL by completing the survey on page 22. This will give us a base of information for *The MBL Project.*
- If you have never tried MBL activities, it's time to get started! Try one of the experiments described in "Probing MBL." Come to **Computers in the Lab: A Symposium for Educators** and attend the **Introduction to MBL Applications Workshop**.
- Develop, adapt, and/or implement MBL materials for your classroom—and share your results with us. We can help you with this much-needed activity. Come to the Symposium and attend the **Developers Workshop**.

We will help you implement MBL activities and develop or adapt your own materials by producing several Developer Tools. Two of the Tools are presently available: *Microcomputers in the Laboratory*, a hands-on manual, and its companion disk. The manual provides an introduction to data acquisition, calibration, and graphing. There are seven starter experiments with instructions for assembling the needed hardware—and other analog interfacing projects. The tools are for Apple II computers. *Microcomputers in the Lab Disk* contains software for the starter experiments illustrated in the manual. See the Reader Response Form for price and ordering information. (Unfortunately, our budget doesn't allow for free distribution.)

We hope to produce other Developer Tools as well. They will be hardware and software kits for the Apple II and the Commodore 64, the computers which the project is using. The *MICROscope* interface will provide convenient access to the Apple's game PADDLE electronics sockets via four analog inputs, two digital inputs, and two digital outputs. It comes with temperature and light sensors and it will work with any of the Apple II series of computers. The accompanying MBL software will include features such as a series of machine-language subroutines for high-speed data acquisition and display. A similar hardware-software kit will be developed for the Commodore 64. Drop a note to Bob Tinker at TERC regarding the availability of these Developer Tools.

If you have ideas or suggestions about MBL activities, we want to hear from you. Contact *The MBL Project* at TERC.

Cluster traditional teaching objectives around interesting problems or topics. Share with us your ideas for experiments, topic areas, probes and software.

Assessing Science . . . Continued from page 3

activities. (Wiser's research is part of a larger study which is being conducted by Harvard's Educational Technology Center.) Like Piaget, Wiser combines clinical questioning with actual demonstrations. Children are asked to predict what will happen when the interviewer manipulates an object. Wiser begins by asking children general questions about heat and cold such as "Where does heat come from?", "Why do you run hot water on jars that are difficult to open?" and "Which has more heat, a large room or a small room?"

In the next phase of the interview, students are asked to make predictions about what will happen when a cylinder filled with alcohol is placed in jars of cold or warm water. In yet another interview, students are given a piece of wood and a piece of marble to hold and are asked, "Is one colder than the other?" "Why?" "Is it really colder or does it feel colder?"

It is easy to see that Wiser's questions probe students' *understanding* of heat and cold rather than their memorization of certain facts. Wiser has gone further than simply describing how children think about heat and temperature. She has developed a conceptual scheme for analyzing their answers and can show which kinds of answers are more cognitively sophisticated than others. One of her primary hypotheses is that children's misconceptions about heat and temperature will in some ways resemble the misconceptions held by a group of seventeenth century scientists. She predicts that children, like early physicists, have a clear yet *undifferentiated* concept of heat and temperature—a concept which is perfectly consistent with their observations of thermal phenomena.

At some point in the future, researchers like Wiser may provide educators with a well-defined hierarchy of how students understand a variety of scientific phenomena. In the meantime, educators can learn a valuable lesson from cognitive psychologists: we need to be concerned not only with what students *know* about science, but with how they *think* scientifically. In order to assess thinking skills in this area—or in any subject area—we need to depend less on standardized tests and more on individual interviews which rely on the child's fluency with concepts. Then we may begin to understand the kinds of experiences children need in order to acquire science skills.

Dr. Janice Mokros is Project Manager and Research Director of the MBL Project.

Researchers are particularly interested in describing the learning experiences and paths that take a person from the status of naive student to "expert."

References

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