APPLE II INTERFACING: HOW TO CONTROL REAL-WORLD DEVICES VIA THE GAME PORT
A Summary of the 1994 ICONference Session by Erick Wagner

About Myself

My name is Erick Wagner. I'm an Apple II enthusiast and an
electronics hobbyist. I began using Apple
II computers, specifically the II+, during the Summer of 1982 while
attending Texas A&M University. I purchased my own computer, an Apple
IIe, towards the end of 1984 and, as a challenge, attempted to interface
my Epson APL printer card with a variety of external devices (LEDs,
electronic drum, etc.). I briefly experimented with an I/O peripheral
card featuring the Motorola 6821 Peripheral Interface Adapter (PIA) chip
and then became distracted with other interests. I did not get back into
computer interfacing until the Spring of 1994, when I enrolled in a
Digital Control Applications course at my local community college. A
6502-based microcomputer trainer was used, the EMMA II from L.J.
Electronics, along with a 6522 Versatile Interface Adapter (VIA) chip to
program its built-in I/O ports and internal timers. This motivated me to
try some new things on the Apple II, including interfacing via the
built-in game ports.

Why Bother?

Question: Why would someone want to interface a computer with a
real-world device?

Perhaps it is the challenge; "because it is there" -- man (sorry ladies,
not trying to be disrespectful) is a curious creature and seeks to
understand and master his environment. Or perhaps there is a real
problem or need that needs to be solved or satisfied.

In case you are having difficulties in thinking of a reason, consider the
following:

o Monitor the pH level in a swimming pool
o Build a home control system
o Build a home security system
o Construct an automated weather station to measure the temperature,
  wind speed, and barometric pressure
o Learn the fundamentals of personal robotics (controlling stepper
  motors and sensors)

Types of Interfaces

PARALLEL - the simultaneous transmission of information over more than
one wire; usually in multiples of 4 or 8. Most modern computers provide
at least an 8-bit data bus but some offer a 16-bit or 32-bit bus.
The most common parallel interfaces are typically used for disk drives or
printers. Some well-known examples include SCSI and the Centronics
interface.

SERIAL - the time-sequential transmission of information over a single
wire. The most common serial interfaces are typically used for
keyboards, mice, printers, and modems. Some well-known examples are
the Apple Desktop Bus (ADB) and RS-232.

DIGITAL - A signal consisting of a group of pulses that are either on or
off; discrete values ("1" and "0") are used.

ANALOG - Circuitry that varies certain properties of electricity (such as
voltage, current amplitude of waves or pulses, or frequencies of waves or
pulses) continuously and smoothly over a certain range, rather than
switching suddenly between certain levels. Signals that do not have
discrete values, but are continuously variable.

GAME PORT - Provides a combination of digital inputs (push button lines
PB0 through PB2 -- or PB3 if you have a IIgs), digital outputs
(annunciator lines AN0 through AN3) and analog inputs (GC0 through
GC3) as well as a strobe output (only for II,II+,IIe).

Choice of Computers

The Apple II series is an ideal platform for learning about computer
interfacing, although other computers are also well-suited for this
task. The reasons in favor of the Apple II include but are not limited
to:

The Apple II series has provided a wide-range of interfaces (slots [II,
II+, IIe, IIgs], cassette in/out [II, II+, IIe], 16-pin game port [II,
II+, IIe, IIgs], 9-pin game port [IIe, IIc, IIc+, IIgs], and serial ports
[IIc, IIc+, IIgs]). Notice that a general-purpose parallel interface is
conspicuously missing.

Today, Apple IIs are relatively inexpensive and readily available. You
can find them at swap meets, consignment stores, garage sales, auctions,
and listed in classified ads.

Items to Consider

In my opinion, the best Apple IIs to use for interfacing would be the
Apple IIe or the IIgs, although a II+ will work just fine. The newer
machines are better equipped to run the latest system software, such as
ProDOS 8, and are more likely to be compatible with today's software.

The closed-architecture machines (IIc, IIc+, Laser 128) provide access to
fewer game port signals and the built-in serial ports are more difficult
and expensive to interface with.

Explanation of Demonstrations

Use of Annunciator Outputs with a Game Port Breakout Box

A custom ProDOS 8 system program and a homemade game port breakout box
were used to "exercise" the annunciator lines of the 16-pin game port.
The system program counted from 0 to 15 and sent the count value to the
appropriate annunciator lines (AN3 AN2 AN1 AN0) so the value could be
"seen" as a 4-bit value. The program used the arrow keys to increase or
decrease the time delay value between each count. A logic probe was used
to sample each of the annunciator output lines and proved that the
computer was in fact doing something.

A-to-D

An inexpensive 10-bit Analog-to-Digital converter (Vernier kit #CAD-16 --
approximately $32) was used to monitor voltage inputs with a program that
simulated a storage oscilloscope. The voltage input sources included a
AA battery (1.5 VDC) and an electric motor which was manually manipulated
to operate as a crude generator. A-to-D (also known as ADC or A/D)
devices measure analog voltages (continuously variable values) and
convert the voltage readings into digital numbers the computer can
understand and work with. The 10-bit digital numbers were sent to the
Apple II in serial format (one bit at a time) by pulsing or not pulsing
the PB2 push button input. The particular integrated circuit (chip) used
for this project was the Linear Technology LTC1092 which outputs it
result in a serial format, rather than the more common parallel output.
This project utilized the 16-pin game port because a couple of the
annunciator output lines were used to control the LTC1092 chip.

Stepper Motor

A Unipolar Stepper Motor was interfaced to the 16-pin game port using the

Allegro Microsystems (formerly Sprague) UCN-5804B integrated circuit
(Vernier kit #CSU-16 -- approximately $16). With this chip, only two
digital output lines (AN0 and AN1) are needed to control a stepper motor;
additional lines could be used to provide even greater flexibility. One
line was used to indicate the direction to turn (clockwise if HIGH or
counter-clockwise if LOW) and the other line wass used to pulse the chip
each time a step is desired. In case you didn't know, stepper motors are
very precise motors which advance one increment each time the electrical
signals to their lead wires are changed. Everyday uses include printers
where they move the print head and rotate the platen and disk drives
where they position the read/write head over the appropriate track. A
program, called MOTOR.TEST, which accompanied the "Chaos in the
Laboratory" book from Vernier Software provides the ability to rotate the
motor in both directions and in three different speeds for the exact
number of steps you specify.

Ultrasonic Range Finder

A Texas Instruments SN28827 module and a Polaroid ultrasonic transducer
were interfaced to the 16-pin game port and used as a range finder
capable of measuring distances ranging from 0.4 meters to 10.7 meters
(1.33 feet to 35 feet). A carefully written (time dependent) program was
used to send out pulses of ultrasonic sound and time how long it took for
the echo to return. Computations based on the speed of sound were then
used to calculate actual distance.

References

Apple II Technical Notes - these can be downloaded from most online
services but a complete set can be purchased from the ByteWorks
(previously, these were available from APDA and Resource Central)

Books - hardware reference section/manual for your computer. Also see
the list at the end of this article

Internet Newsgroups (Usenet) - check out the computer, electronics, and
robotics forums

Online services (e.g., GEnie, CompuServe, America Online)

Magazines - see the list at the end of this article

User groups (e.g., computer, robotics) - visit or join your local
computer and robotics user groups. You will definitely learn something
new, make some new friends, and locate your local experts.

Equipment and Tools

Computer - this one's kind of obvious isn't it!

Game Port Extender - a special extension cable which plugs into the
16-pin game port connector (II,II+,IIe,IIgs) on the motherboard and makes
available a zero insertion force (ZIF) socket which is mounted outside of
the computer. This makes the task of plugging and unplugging devices
much less frustrating! Otherwise you have to: (1) "pop the lid" of your
machine, (2) use a chip puller to remove the existing device from the
16-pin game port connector, (3) feed the plug of the new device through
one of the holes on the back of the computer, (4) insert the new device
into the socket with the correct orientation and without bending or
breaking any pins, (5) replace the cover. With the ZIF, you simply: (1)
move the lever in one direction to release the grip and easily lift out
the current device's plug, (2) insert the plug of the new device, (3)
move the lever back to lock it into place. Approximate cost is $16.

Power Supply - If the devices you plan on hooking up to your computer
require a significant amount of current (100 mA or more) or require
voltages which are not available (anything but +5 V), you will need
to purchase an external power supply. Be sure to get one that can supply
more current than you will need; an ampere rating of 2 or 3 Amps should

be plenty unless your equipment is power hungry. Be aware that when more
than one power source is used (+5 V from the game port counts as a power
source) and when one or more peripheral circuits are used together with
the computer, you must USUALLY have the ground connections (Gnd) all tied
together. Also, if you are using a high-efficiency switching power
supply to power your external circuits, be aware that the supply might
require a MINIMUM current draw to prevent damage to the power supply.
For example, I have a Happ Controls, Inc. 80-0016-00 12 Amp Switching
Power Supply and it has a warning label which reads "Supply outputs must
be connected before applying line voltage. Failure to do so may result
in damage to internal components and will void warranty." If it is a
multi-voltage supply, then each output (+5 V, -5 V, +12 V) must have some
type of load circuit attached before applying power.

Logic Probe - an optional but handy device that can be used to "look"
into a digital circuit and determine if a signal is either high ("1") or
low ("0"). Most models provide multicolor LEDs and a tone generator to
provide visual and auditory feedback. Approximate cost is within $20.

Digital Multimeter - this is probably one of the most important pieces of
test equipment you can own. You only need the basic functions: DC
voltage and resistance. The resistance mode is useful for testing
continuity (determining whether a connection is broken); a resistance of
zero indicates a good connection, an infinite reading indicates an open
in the circuit. Approximate cost is within $30.

Hand Tools - electronics work is done with relatively small components,
therefore use the correct size tools. Please don't use the same tools
you use to work on the car or the kitchen sink; they're too big and
probably not very clean. Your tools should include: a pair of needlenose
pliers, wire snips, screw drivers (both kinds), and a chip puller.

Soldering Iron - use a low-wattage (between 15 to 40 watts) soldering
iron, pencil, or station. DO NOT use a soldering gun; these weapons are
dangerous to semiconductor devices in terms of heat and the electricity
flowing through the tip. Be sure to keep a damp sponge nearby to
periodically wipe off the tip of your iron.

Wire Wrap Tool - wire wrap is an alternative to soldering and provides
good solid connections superior to those of a solder joint. Wire wrap
connections can also be removed very easily (by unwrapping the
connection). In fact, a lot of electronic circuitry is prototyped using
wire wrap because of the ease of revision. Wire wrap requires use of a
special wrapping tool, a supply of 30-gauge wire, and IC sockets or
mounting posts which are specifically designed for wire wrap.

How To Get Started

Learn about the internals of your machine. Get familiar with the memory
map of the Apple II. The $C0 page ($C000 through $CFFF) is reserved for
memory mapped I/O and softswitches.

Learn about and understand the binary, decimal, hexadecimal numbering
systems.

If you are a complete novice, you might begin by purchasing a low-cost
kit or attempting a very simple project. The kits from Vernier Software
are ideal but feel free to use any similar materials. Depending on
your construction skills (e.g., soldering, wire wrap) you may need to
learn or practice until you feel comfortable. By all means, take your
time. You're supposed to have fun!

You might also want to build a game port breakout box. This is a very
useful, low-tech device which permits easy access to each signal
available on the 9-pin and 16-pin game port connectors. Typically, the
lid of a plastic box is replaced with a piece of perfboard that has been
cut to match. Two of each type game port connector (DB-9 female and
16-pin DIP) and a connector (I used "RCA" phono jacks) for each
game port signal is mounted on the perfboard. A faceplate can be
utilized to help label each of the game port signal connectors.

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Pinouts
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16-pin Dual Inline Package (DIP) socket for II+, IIe
            +-v------+
+5 V        | 1   16 |      Not used
PB0         | 2   15 |      AN0
PB1         | 3   14 |      AN1
PB2         | 4   13 |      AN2
Strobe      | 5   12 |      AN3
GC0         | 6   11 |      GC3
GC2         | 7   10 |      GC1
Gnd         | 8    9 |      Not used
            +--------+


16-pin Dual Inline Package (DIP) socket for IIgs
              +-v------+
+5 V          | 1   16 |    Not used
PB0           | 2   15 |    AN0
PB1           | 3   14 |    AN1
PB2           | 4   13 |    AN2
+5 V pullup   | 5   12 |    AN3
GC0           | 6   11 |    GC3
GC2           | 7   10 |    GC1
Gnd           | 8    9 |    PB3
              +--------+


DB-9 Connector
+--------------------+
  \ 5   4   3   2   1 /
   \  9   8   7   6  /
    +--------------+

(View: Looking at female connector on the back of the Apple
IIc,IIc+,IIe,IIgs)


1=PB1          2=+5 V          3=Gnd
4=GC2          5=GC0          6=PB2
7=PB0          8=GC1          9=GC3
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+5 V   - Total current drain on this pin must be less than 100 mA
AN0   - Annunciator 0 output. The output is capable of sourcing 0.4 mA
at 5 V in its logic 1 state, or it can sink 8 mA in its logic 0 state.
AN1   - Annunciator 1 output.
AN2   - Annunciator 2 output.
AN3   - Annunciator 3 output.
GC0   - Game Controller 0 input. An analog input designed to accept a
variable resistance in the range of 0 to 150 K (ohms). Each GC input is
part of an analog-to-digital (A-to-D or A/D) conversion circuit
that allows an analog resistance value to be converted into a digital
quantity. The resistance forms part of a simple "RC"
(resistor-capacitor) timing circuit that sets the time constant for the
558 integrated circuit (a quad version of the 555 Timer).
GC1   - Game Controller 1 input. Same as GC0.
GC2   - Game Controller 2 input. Same as GC0.
GC3   - Game Controller 3 input. Same as GC0.
PB0   - Push Button 0 input.
PB1   - Push Button 1 input.
PB2   - Push Button 2 input.
Strobe - Normally kept at a high logic level (+5 V), this signal goes
low (near 0 V) for half of a clock cycle any time an address in the range
$C040 through $C04F is accessed. Can be used to send a momentary pulse
(a "strobe") to an external circuit. Such a pulse may be required to
change the state of an on/off device or to latch data into the circuit so
that it will not change until after it has been read or sent.

Apple Tech Notes

Apple IIe Tech Note #6: The Apple II Paddle Circuits
Apple IIe Tech Note #9: Switch Input Changes

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Books
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"Apple Connection, The", James W. Coffron, Sybex, ISBN: 0-89588-085-7
"Apple House, The", John Blankenship, Prentice-Hall, Inc., ISBN:
0-13-038711-8
"Apple II Assembly Language", Marvin L. De Jong, Howard W. Sams & Co.,
ISBN: 0-672-21894-1
"Apple II Applications", Marvin L. De Jong, Howard W. Sams & Co., ISBN:
0-672-22035-0
"Apple II - 6502", Richard Haskell, Prentice-Hall, Inc., ISBN:
0-13-039230-8
"Apple Interfacing", Jonathan A. Titus, David G. Larsen, Christopher A.
Titus, Howard W. Sams & Co., ISBN: 0-672-21862-3
"Apple Programmer's Handbook", (Chapter 8), Paul Irwin, Howard W. Sams &
Co., ISBN: 0-672-22175-6
"Build Your Own Universal Computer Interface", Bruce Chubb, TAB Books,
ISBN: 0-8306-3122-4
"Chaos in the Laboratory", David L. Vernier, etal, Vernier Software,
ISBN: 0-918731-46-1
The "Ciarcia's Circuit Cellar" series, Steve Ciarcia, Byte
Books/McGraw-Hill, these are reprints from his Byte Magazine column
"Custom Apple & Other Mysteries, The", IJG, Inc., Winfried Hofacker,
Ekkehard Floegel
"Hardware Interfacing with the Apple II Plus", John E. Uffenbeck,
Prentice-Hall, Inc., ISBN: 0-13-383844-7
"How to Build a Better Mousetrap and 13 Other Science Projects Using the
Apple II", David L. Vernier,
Vernier Software, ISBN: 0-918731-16-X
"Interface Projects for the Apple II", Richard C. Hallgren,
Prentice-Hall, Inc., ISBN: 0-13-469387-6
"Interfacing & Digital Experiments with your Apple", Charles J.
Engelsher, Tab Books, Inc., ISBN: 0-8306-1717-5
"Programming & Interfacing the 6502, With Experiments", Marvin L. De
Jong, Howard W. Sams & Co., ISBN: 0-672-21651-5

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Magazines
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Byte (look for the Circuit Cellar column by Steve Ciarcia)
Computer Applications Journal, The (Circuit Cellar Ink -- Steve Ciarcia)
ComputerCraft (became MicroComputer Journal with Jan/Feb 1994 issue)
Electronics Now
InCider (look for the early issues before the merger with A+)
MicroComputer Journal (formerly ComputerCraft)
Modern Electronics
Popular Electronics
Radio Electronics
Science Probe (look for the Computer Scientist column)

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Resources
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Byte Works
8000 Wagon Mound Drive N.W.
Albuquerque, NM 87120
(505) 898-8183
America Online: MikeW50@aol.com
GEnie: ByteWorks@genie.com
GEnie: Category 45 of the A2 (m645) Bulletin Board and Category 36 of
A2Pro (m530) Bulletin Board

Vernier Software
8565 S.W. Beaverton-Hillsdale Hwy.
Portland, OR 97225-2429 USA
(503) 297-5317
Internet Mail: dvernier@vernier.com
They sell books, hardware, software, and cables for the Apple II, Mac,
and PC

[Vernier Software has been producing laboratory interfacing software
since 1982. They specialize in assisting schools teach scientific
principles by using personal computer technology. So, if you are
affiliated with a school or just an interested hobbyist, they certainly
offer some interesting products (books, kits, sensors, probes,
interfaces, cables, software). They currently support the following
platforms: Apple II (game port, peripheral slot card), IBM PC (game port,
peripheral slot card, serial interface), and Macintosh (serial
interface). Call, write, or email for a current catalog.]

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