Peter G. Aitken

DIGITAL-TO-ANALOG

ANALOG-TO-DIGITAL

The Tecmar Lab Master Board interfaces with the PC to bring efficiency to the lab

Many computer applications require that the computer be able to communicate with the real world in a manner not possible with keyboard, printer, or modem. Tasks such as laboratory data collection or industrial process control are possible only if the digital world of the computer can be interfaced in real time to the analog world of temperatures, weights, voltages, etc. If a computer can be set up to sense and control analog processes, its calculational and storage capabilities can be put to excellent use in many situations. The Lab Master, manufactured by Tecmar, provides just such an interface for the IBM PC or XT. In addition to its analog-to-digital (a/d) and digital-to-analog (d/a) capabilities, the Lab Master provides counting, timing, and digital input/output features, all of which make up a sophisticated and powerful interface.

Let's take a look at the Lab Master. It consists of a full-size mother board (see figure 1) that is plugged into one of the PC's slots, plus a metal box (approximately 10"x2"x6" containing the daughter board, which is connected to the mother board by a 50-conductor ribbon cable about 3 feet long. A/d conversions are performed on the daughter board, while all other functions are handled on the mother board. This arrangement has the advantage of allowing the a/d converter to be located near the source of the signal and outside the electrically noisy environment of the PC's cabinet (the ribbon cable between the mother and daughter boards can be greatly extended.

Packed into the mother and daughter boards are sixteen single-ended or eight differential a/d channels, two d/a channels, five to sixteen bit timers/counters, and twenty-four digital input/output lines.

Analog-to-Digital Converter

The Lab Master's standard a/d converter has a rated maximum conversion rate of 30KHz, although mine operates at 40KHz with complete reliability. The full-scale input range is jumper selectable for 0 to +10v or −10 to +10v; it is a 12-bit converter, meaning that its resolution is one part in 2^{12}, or 1/4096 of the full-scale range. This means, for example, that an input signal of 0 to +10v will be measured with an accuracy of approximately 0.0025v.

The a/d converter has an autoincrementing feature that can free the software from the necessity of specifying the input channel to convert for each conversion. When autoincrementing is enabled (via a software command), the a/d converter will automatically cycle between a starting channel (specified by software) and a final channel (set with a DIP switch on the daughter board).

In addition to its input range, several other operating parameters of the a/d converter must be selected by installing jumpers over pins on the daughter board. These parameters include single-ended or differential inputs, output data format (two's complement or binary), and others, covered in the instruction manual.

There are a number of extra-cost a/d options available: expansion to 256 input channels; software-programmable gain up to 500; hardware-selectable (via a resistor placed on the daughter board) gain up to 2000; 14- or 16-bit conversion accuracy; and 100kHz maximum conversion rate. Some of these options are mutually exclusive, however; 14 and 16 bit converters are limited to maximum conversion rates of 10 and 2.5 kHz, respectively. In addition, input gains greater than 10 require that a capacitor be placed on the daughter board to allow for longer amplifier settling times. This reduces the maximum conversion rates: e.g., 20kHz at a gain of 100 and 3.8 kHz at a gain of 1000.

Converters and Timer/Counter

The Lab Master has two independent d/a converters (DAC80s). Each converter has a 12-bit input, 5-microsecond settling time, and jumper selectable output ranges of −2.5 to +2.5, −5 to +5, −10 to +10, 0 to +5, or 0 to +10 volts.

The Lab Master's timing and counting functions are provided by an AM9513 LSI chip. This is an extremely sophisticated chip that can provide almost any conceivable timing or counting function, if the required programming can be figured out. It consists of five general-purpose 16-bit counters, frequency dividers, and a variety of special-purpose registers. Some of the tasks that can be accomplished with this chip are the time of day, an external-event counter, and the generation of complex timing patterns.

The 9513 is accessed through only two ports: a data port and a control port. Inside the 9513 are, by my count, 20 control and data registers that must be accessed through these two ports (see figure 2). This is done by sending a command specifying one of the internal registers, and then sending a read or write command. This system works, but it leads to some rather complex programming.

Parallel Ports

There are twenty-four parallel digital input/output lines on the Lab Master, provided by an Intel 8255. These lines can be programmed as groups of eight or as groups of twelve. There are three modes of operation available: three input or output ports, two input or output ports with handshaking, or a bidirectional I/O port with handshaking (see table 1).

Interrupts

An interrupt allows the processor to respond to a signal from an external device without having to constantly check ("poll") to see if the signal has been sent. When a signal is received on an interrupt line, the processor saves the relevant information about its current task and then executes a series of software instructions located at a predetermined memory location. These instructions, called an interrupt handler, perform the tasks needed to "service" the interrupt, and the processor then resumes the task that was interrupted.

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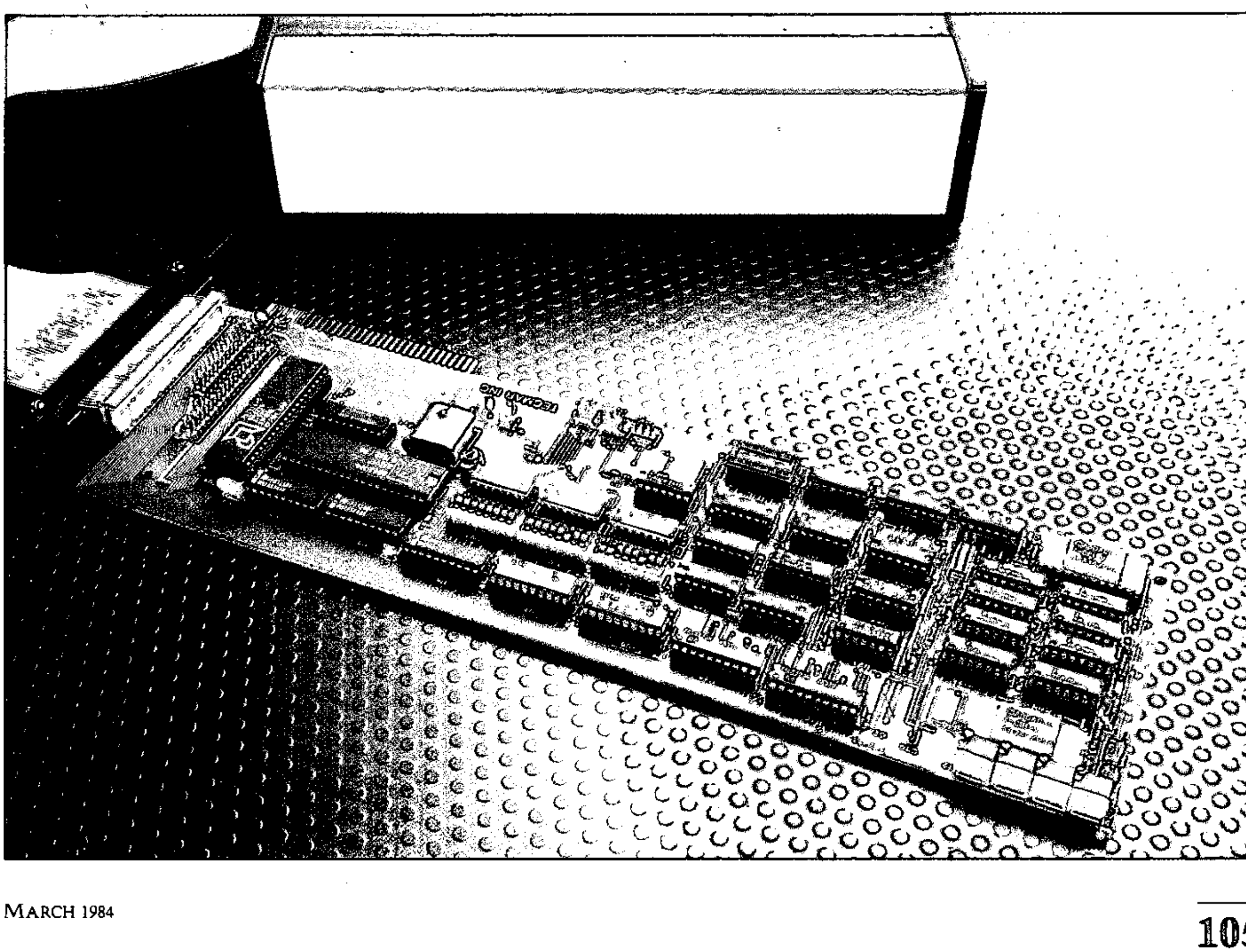

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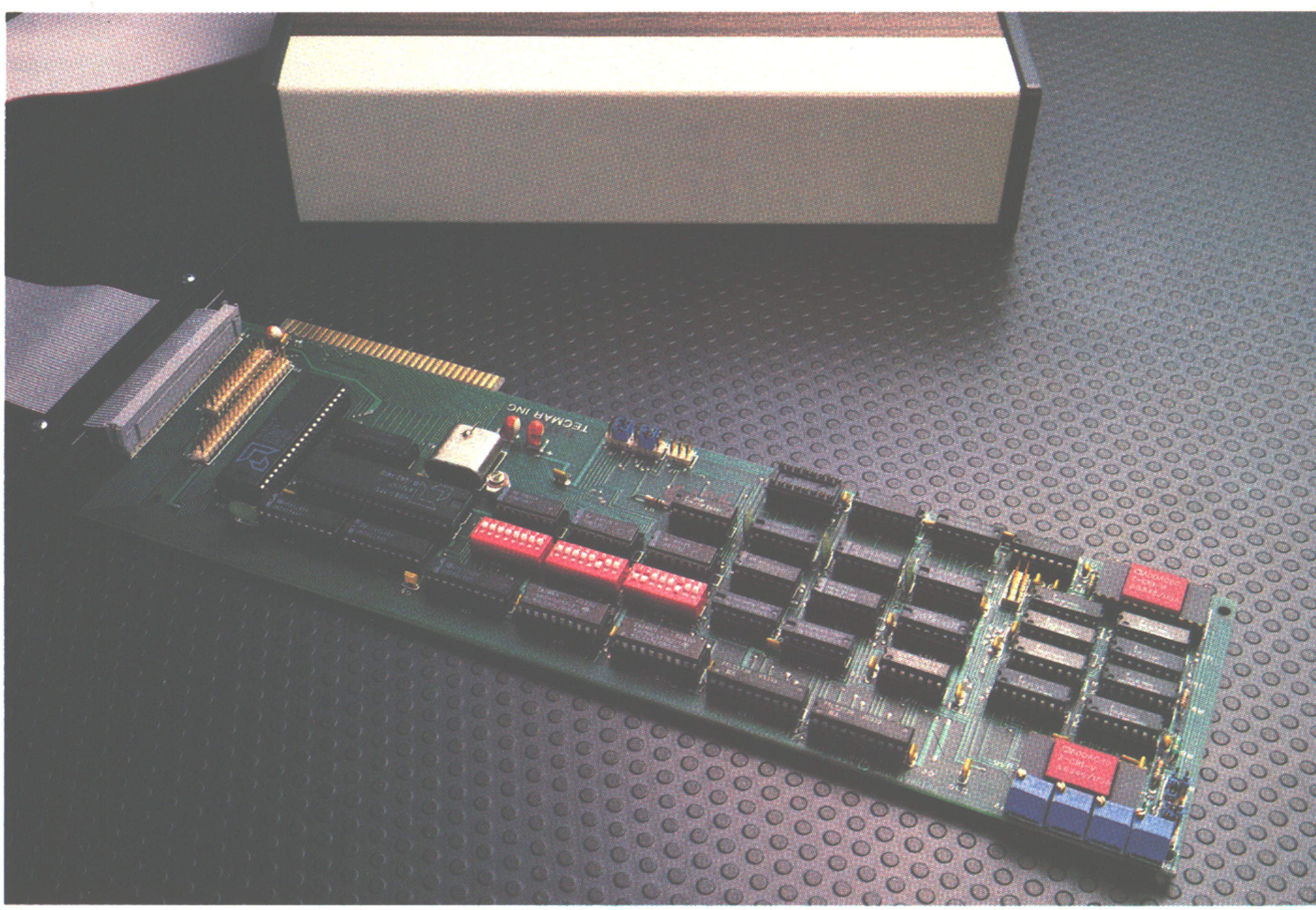

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LAB MASTER

Figure 1: Block Diagram of Lab Master Mother Board. (Reprinted from the Tecmar Lab Master Board manual by permission of Tecmar Inc.)

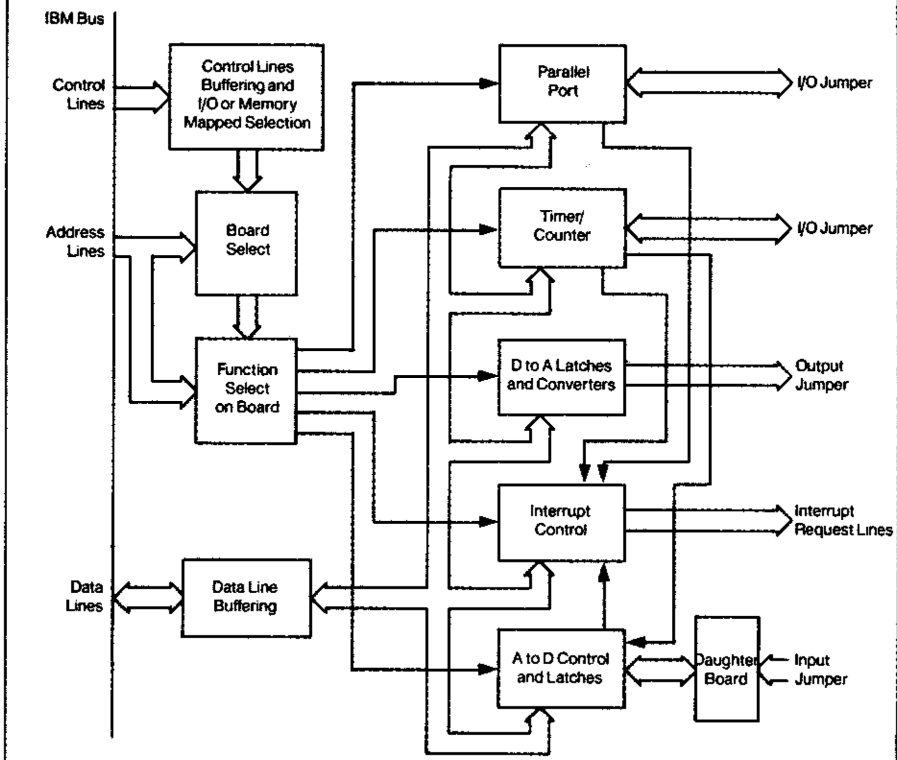
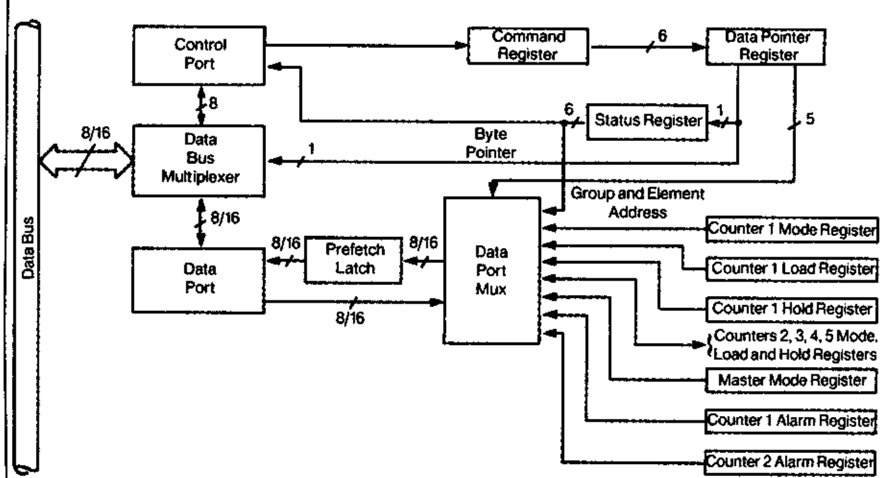


Figure 2: Block Diagram of Register Access for 9513 Timer. (Reprinted from the Tecmar Lab Master Board manual by permission of Tecmar Inc.)



The Lab Master allows access to interrupt lines 2 through 7 in the PC and permits interrupts to be generated by the a/d converter, timer, or parallel ports. Thus, as many as six interrupt service routines can be in place at one time. Interrupt sources are joined to interrupt lines with jumpers on the mother board.

The interrupt feature can be extremely useful. For example, imagine an application requiring that an a/d conversion be done once per second over a long period. The Lab Master could be configured so that one of the clocks caused an interrupt once per second, jumping to an interrupt-handler routine that initiated an a/d conversion and stored the data in memory. Since this task would require only a few milliseconds out of each second of the computer's time, the computer can be busy with another task— such as data processing or program editing—with the time spent collecting data not even noticed by the operator.

Some confusion may result from the fact that the IBM PC interrupt lines (IRQ2 through IRQ7) are numbered differently from the 8088's interrupt types: the PC's interrupt line IRQ2 is not an 8088 type-two interrupt. This fact is not mentioned in the Lab Master manual, but a call to Tecmar revealed that the 8088 interrupt type is the IRQ number plus eight, and the vector table address for a given interrupt type is equal to the interrupt type times four. Thus, a signal on IRQ line five will generate a type-13 interrupt, causing a jump to the interrupt-service routine whose starting address is stored in the interrupt vector table at memory locations 00034H (instruction pointer) and 00036H (code segment). See *The 8086/8088 Primer* by S. P. Morse (Hayden Book Co., 1982).

PROGRAMMING

The Lab Master may be configured in a memory mapped or an I/O mode. In the memory mapped mode, it appears to the computer as 16 consecutive memory locations; in the I/O mode it appears as 16 consecutive I/O ports. The board comes from the factory in the I/O mode with starting address 0710H. These 16 ports are the computer's means of communicating with the Lab Master; through them, data and status can be input from the board and control commands can be output to the board. Only two software commands are needed to use the Lab Master; in BASIC, these are INP and OUT (for the I/O mode) or PEEK and POKE (for the memory mapped mode).

Table 1: Tecmar Lab Master Port Assignments

STARTING ADDRESS PLUS	READ	WRITE
0	*	low 8 bits for D/A #0
1	*	the low 4 bits of this byte are the high 4 bits for D/A #0
2	*	low 8 bits for D/A #1
3	*	the low 4 bits of this byte are the high 4 bits for D/A #1
4	Status byte—individual bits indicate status of specific board functions.	Control byte—individual bits control certain board functions
5	Low A/D data byte	A/D channel number to convert
6	High A/D data byte	Software start conversion—writing anything to this location initiates an A/D conversion.
7	*	Timer interrupt acknowledge
8	Read data port of 9513 timer	Write to data port of 9513 timer
9	Read control port of 9513 timer	Write to control port of 9513 timer
10	*	*
11	*	*
12	Parallel port A input	Parallel port A output
13	Parallel port B input	Parallel port B output
14	Parallel port C input	Parallel port C output
15	*	Parallel port control byte

*means not used

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The 8088 uses an 8-bit data path, yet there are times when 12, 14, or 16 bits of data must be sent to or received from the Lab Master. Such transfers require two commands, one to transfer the lower 8 bits and one to transfer the higher 8 bits. Thus, for example, to input a value from the a/d converter the following steps must be taken (assuming that the Lab Master is I/O-mapped at starting address 0710H and is jumpered for a −10 to +10v input range and two's complement data):

```
90 REM—start a conversion
100 OUT 0716H,0
110 REM—bit 7 of status byte set
  ( i.e., conversion done)?
120 IF INP (0714H) THEN 120
130 REM—not get the data
140 LOW.DATA=INP(0715H)
150 HI.DATA=INP(0716H)
160 REM—convert from two's
  complement to a voltage −10
  to +10
170 VOLTS=(256*HI.DATA)+
  LOW.DATA
180 VOLTS=VOLTS/204.8
```

When programming in assembly language, the two necessary byte transfers can be accomplished with one IN or OUT command.

THE MANUAL

The installation and instruction manual for the Lab Master is sized to fit in one of IBM's binders. In general, it is clear and complete, although there are areas in which some more information would be welcome (e.g., on programming interrupts). Several sample programs (all in BASIC) are provided. The one major weak point of the manual is the section on the 9513 timer/counter. As mentioned before, this device is rendered somewhat difficult to program by its two-port configuration and by the complexity of the functions available. The manual seems to provide all the needed information, but it is hard to understand. Particularly helpful here would be a number of sample programs for setting up the 9513 to do a variety of the most common tasks.

LAB MASTER

PERFORMANCE

The Lab Master in this laboratory has been in fairly constant use for almost a year now. We have used most of the functions, and, with one exception, the Lab Master has performed perfectly. This one exception involves the 9513 timer chip; occasionally (perhaps once in 300 tries) the chip would not obey a software command to start a clock running. The people at Tecmar felt that this problem was internal to the 9513 itself, and they sent me a replacement chip. Installing the new 9513 reduced the problem (to about 1 failure in 2000 tries), but did not completely solve it. I got around this problem by having my programs send the "start clock" command twice.

SOFTWARE

According to the advertising literature, Tecmar's LABPAC, a package of software routines written for the Lab Master, will provide "a library of powerful real-time facilities [which will] permit the user to write programs in BASIC, FORTRAN, PASCAL, or Macro assembler using LABPAC commands as though they were part of the program itself." Included will be analog input, analog output, timing, digital input and output, and graphics. Unfortunately, this software is not currently available.

CONCLUSIONS

Tecmar's Lab Master board provides a powerful, flexible interface for the IBM PC. At present, however, it is not supported by software. Until the LABPAC package becomes available, the Lab Master should be considered only when the requisite programming skills are available. In such situations, the Lab Master should function admirably—in fact, we have found it so valuable that we are buying another identical system.

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