Real-time data acquisition system
for laser and radio-frequency spectroscopy

T Brenner, S Büttgenbach#, T Fabula and W Rupprecht

Institut für Angewandte Physik der Universität,
Wegelerstrasse 8, D-5300 Bonn 1,
Federal Republic of Germany

#Present address: Institut der Forschungsgesellschaft für Feingeräte-, Mikro- und Uhrentechnik e.V.,
Breitscheidstrasse 2 b, D-7000 Stuttgart 1,
Federal Republic of Germany

Keywords
real-time data acquisition system, personal computer, laser spectroscopy, radio-frequency spectroscopy

Short title: Real-time data acquisition system

Abstract. A low-cost real-time data acquisition system utilizing a master (PC-XT) and a slave (Z80) computer for high-resolution atomic spectroscopy is described. The master and the slave computer are linked by a high-speed parallel FIFO-buffer permitting data acquisition on a fixed time schedule with 4 μs time resolution. A modular interface box allows the system to control complex spectroscopic experiments. The use of commercial software packages allows fast and efficient data reduction and analysis on the same computer system. The performance of the system has been demonstrated in a polarization spectroscopy experiment on Zirconium.

1. Introduction

Spectroscopy, i.e. the study of emission and absorption of electromagnetic radiation by matter, is the main source of our information about atomic structure.

Two principle experimental techniques have been applied by our group for the investigation of atomic fine and hyperfine structure. The atomic beam magnetic resonance method in combination with state-selective laser-induced detection of rf-resonant atoms has been used to measure hyperfine structure splittings and g_J factors of metastable states with high precision (Brenner et al 1985). In addition, Doppler-free laser spectroscopic methods have been applied to study isotope shifts and hyperfine structures of atomic transitions starting from metastable levels (Bourauel et al 1987).

In order to achieve high accuracy and sensitivity in such experiments fully computer-controlled spectrometers have to be used especially in the case of weak and/or perturbed signals. The data acquisition system of such a spectrometer should be able to control the experiment in real time and to process a large amount of data in a fast and reliable manner. In this paper we describe a versatile PC-based data acquisition system that meets these requirements.

2. The hardware of the system

Several criteria need to be considered in designing and implementing a data acquisition system for the control of high-resolution laser and rf spectrometers. The response time of the system should allow real-time applications with no limits set by the operating system (e.g. interrupt handling). In addition, the whole system should be constructed in a modular way so that it may be used to control various experimental setups with a minimum of hardware and interface modifications. Furthermore,

the system should be easy to use and to maintain, and it should allow fast and efficient program development.
In order to satisfy these requirements we chose a two-processor-system configuration which offers the advantage of separating the tasks of fast data acquisition and time consuming data processing.

The hardware of the system comprises four main parts:

(1) The PC master computer, which uses a high-level user friendly operating system, interfaces with the user and controls the data analysis and storage.

(2) The Z80 slave computer, which manages the timing and the real-time data acquisition and controls the experiment.

(3) The FIFO-buffer (First-in-first-out), which allows an asynchronous communication and buffering of the transmitted data, provides the real-time capability of the slave computer.

(4) The interface box, which contains several standardized I/O-modules, that link the system to the spectrometer. Figure 1 shows a block diagram of the whole system.

2.1 The PC master computer

An IBM-compatible personal computer (PC-XT, 8088/8 MHz) with 640-kByte memory and a numeric coprocessor (8087/8 MHz) was selected as master computer because of its versatility and the availability of commercial hardware extensions and software packages. The system uses a 32-MByte NEC harddisk and two floppy drives (1.2 MByte/360 kByte) for storage of programs and spectroscopic data. In addition, the system includes a high resolution monochrome monitor, a HERCULES-compatible graphics card and an EPSON FX-100 printer. Input/output is controlled by a multifunction card containing two serial ports, an additional parallel port and a real-time clock. A homemade parallel interface card is used to connect the master computer to the slave computer. This interface card is equipped with 96 parallel I/O-ports mounted on a PC-prototype board. In order to avoid stray pickup and to suppress signal distortion dual-line drivers/receivers (TEXAS INSTRUMENTS SN72172, SN72173) buffer the data channels between the master and the slave computer. An optional HP IEEE-488 interface card may be used to link commercial measurement equipment, for example a TEKTRONIX storage oscilloscope (model 2230) or a HEWLETT PACKARD dynamic signal analyzer (model 3561A).

2.2 The Z80 slave computer

The Z80 slave computer consists of a modular ECB (Europe card bus) system containing the following components:

(1) A Z80-CPU card (CMOS, 4 MHz) with 32-kByte static RAM, two parallel ports (Z80-PIO) and a ROM-resident FORTH-kernel (32-kByte EPROM).

(2) A timer card (4 x Z80-CTC), which generates timing intervals from 4 μs to about 10^5 days, for the exact timing of the measurements. These four timers manage the temporal interaction of the whole system and render complex measuring-time schedules possible.

(3) A parallel interface card (4 x Z80-PIO) to control the interface box.

(4) A serial interface card (3 x Z80-SIO) for communication with the laser control interface (Kress 1985) and RS-232 terminal communication (19.2 kBaud) with the master computer.

(5) An interface box driver card to maintain signal amplification of the I/O-modules.

In order to set up the slave computer for operation, its FORTHinterpreter waits for control words sent by the PC master computer, which operates as a RS-232 terminal. During an experimental run the high-speed transmission of spectroscopic data takes place via the FIFO-buffers.

2.3 The FIFO-buffer

When developing computer programs for a two-processor-system special care has to be taken in organizing the data transfer between the two computers. As in our case the slave computer has to run on a fixed time schedule (real-time data acquisition), having to wait for the readiness of the master computer for sending or receiving data must be avoided.
Programming is facilitated by buffering the data flow between the computers with a FIFO memory buffer. A FIFO-buffer consists of a memory with separated input and output port. The incoming words are put on a stack. A word is read from the FIFO by removing the word from the bottom of the stack. In this way the stack preserves the temporal order of the data stream. Both master and slave computer have independent access to the FIFO-buffer. There are two FIFO-buffers per data direction (see figure 2). The slave processor can write data directly into the <u>input</u> FIFO (DATA-IN, DATCTRL); the <u>output</u> FIFO (DATA-OUT) provides data from the master computer. Using the FIFO-buffers there are three constraints:

a) The master computer has to empty the input FIFO in time to avoid a full stack.

b) The master computer has to fill the output FIFO before the slave computer begins to read the data.

c) The memory size (stack depth) of the FIFO-buffer must be large enough to prevent stack overflow.

Therefore a software protocol manages the FIFO operation. The status of the FIFOs is shown by the signals 'stack full' and 'stack empty'. The master computer uses the signals to serve the FIFOs. As for the slave computer, at least the input FIFO always has to show that it is ready for data transfer. In order to detect errors in the data transfer timing, the slave com-

puter also checks the status signals before reading and writing.
The FIFO-buffer we used is the Zilog Z8038-FIO (FIFO Input-Output) which has a stack depth of 128 words and a width of 1 byte. Width and depth can easily be expanded by cascading the FIOs. The FIFO-buffers are connected on the one side directly to the Z80 system bus, on the other side they communicate via two wire handshake with peripheral parallel I/O ports (8255 PPI) of the PC. The status and the control signal pins of the FIOs are also connected with parallel I/O ports (PIO and PPI) on both sides.
The time necessary for data transfer from a peripheral device (e.g. photon counters) through the FIFO-buffer to the master computer takes less then 10μs corresponding to a data rate of approximately 10^5 words (16 bit) per second. Figure 2 shows a scheme of the communication between the master and the slave computer.

2.4 The interface box

A standard interface bus system has been implemented to guarantee high flexibility. The interface modules are controlled by 8 CONTROL lines and selected by 8 ADDRESS lines allowing a maximum of 256 I/O-modules to be addressed. 16 DATA-IN and 16 DATA-OUT lines transmit information from or to the spectrometer.

The hardware of the interface box consists of the following modules (see figure 3):

(1) A voltage-to-frequency converter module (BURR-BROWN VFC 62) with two channels for voltages between 0 - 2 V and 0 - 10 V, respectively.

(2) A counter card (two 32-bit TTL-channels) to acquire calibration and measuring signal counts. The maximum counting rate is 50 MHz.

(3) A counter card (two 32-bit ECL-channels) for fluorescence photon counting up to a maximum counting rate of 150 MHz.

(4) A radio-frequency decade (SCHOMANDL MG520M, 1-520 MHz) parallel interface card for rf-spectrometer use.

(5) A single-bit I/O-card (16 bit) to control error signals which may occur during the experimental run.

A standardized 19" housing contains the Z80 slave computer and the interface box. Due to the modular design of the interface box a maximum of flexibility has been achieved allowing modifications and replacement of ECB- or I/O-modules without affecting the rest of the acquisition system.

3. The software of the system

The software is divided into two independent programs since the Z80 slave computer is responsible for real-time data acquisition and the PC master computer for the data processing and storage. The software is written in the FORTH programming language (Laboratory Microsystems 1984) in order to facilitate convenient operation with large portions of data without a 64-kByte limit and to provide for the possibility of including machine language routines for direct memory control and I/O-port access. The FORTH-kernel of the slave and all its primitives (e.g. master communication, counter control, setting of the rf decade) are ROM-resident in order to simplify an autonomous operation of the slave computer. The actual measuring program is loaded from the harddisk into the Z80 RAM-memory by the user. Program modifications and maintenance can easily be performed at the PC-console. The PC-resident terminal program also enables the user to modify parameters or even the measuring program, and to log on to the slave system. Before an experimental run the user is able to switch between the master and the slave, to check the I/O-modules and the status of the slave computer. During the measurement the data acquisition system operates under full slave computer control.

The operation software of the two-processor-system provides for the following options:

<u>Slave:</u>

* Control of the spectroscopic experiment in real time. This includes sweeping of the dye laser and of the rf decade and reading the counters.

* Preprocessing of the incoming data and transmission to the master computer through the FIFO-buffers.

<u>Master:</u>

* On-line display of the fluorescence spectrum on the monitor.

* Storage of fluorescence and calibrating etalon signals along with the operational parameters on the harddisk.

* Menu control in order to guide the user through the experiment and to provide convenient help facilities.

The master PC also offers sufficient computing power for off-line analysis of the measured data (Lorentzian/Gaussian curve fits). These may be compared with the results of a spectra simulation program written in Turbo-Pascal (Borland International 1985). A hardcopy of the spectra may be sent to a graphics printer or to a plotter with no loss of resolution. For further mathematical processing of the measured spectra the spectroscopic data may be transferred to commercial software packages (e.g. ASYST, SYMPHONY) or even to an IBM 3081 mainframe with advanced capabilities.

4. Polarization spectroscopy of Zirconium

The performance of the data acquisition system has been checked by measuring isotope shifts of Zirconium by laser polarization spectroscopy in a hollow cathode discharge. A schematic diagram of the experimental arrangement used is shown in figure 4. The laser system used in these experiments is a COHERENT RADIATION (CR 699-21) single-mode dye laser pumped by a SPECTRA PHYSICS Argon-ion laser. The single-mode operation of the laser is monitored by a scanning Fabry-Pérot interferometer (2 GHz free spectral range). The frequency scan of the laser is calibrated with a fixed 60 MHz reference cavity (Büttgenbach and Küpper 1986) and the fringes are monitored on the data acquisition system along with the polarization spectroscopic signal. In order to find the proper wavelength a digital wavemeter with a Zeeman stabilized He-Ne reference laser is used. The laser frequency is swept and the polarization signal is detected phase sensitively by a lock-in amplifier (ITHACO 5205). A typical spectrum corresponding to the transition $a^3F_2 \rightarrow z^5F_1$ in ZrI (λ = 595.5 nm) is shown in figure 5. In the upper part of figure 5 the 60 MHz fringes used as frequency markers are shown. In this way isotope shifts of the neutral Zirconium atom have been measured by Doppler-free laser polarization spectroscopy (Bourauel et al 1987). Hyperfine structure measurements and the results of a parametric analysis of the hyperfine structure and isotope shifts will be published elsewhere (Büttgenbach and Rupprecht 1988).

5. Conclusion

A PC-based data acquisition system has been proved to be a powerful instrument for use in rf and laser spectrometers with a wide variety of applications. The system, based on an IBM-compatible PC and a Z80 slave computer, was successfully applied in high resolution laser polarization spectroscopy.

The realization as a two-processor system has the advantage of a very fast system response. Data acquisition and controlling an experiment can be performed with a time resolution of at least 4 μs. Programming the system without complex interrupt handling routines is possible by virtue of the excellent real-time capability of the slave computer, a capability based mainly on the independently working FIFO-buffers. The system consists of standardized components and is widely expandable. Hardware expansions might consist of additional interface moduls (e.g. A/D-, D/A-converters) as well as replacing the PC-XT console with a PC-AT (16 bit) or even a 32-bit-technology computer with no need for further hardware modifications.

The ability to analyze the spectroscopic data immediately on the same computer is an appealing feature. Future versions of the software will utilize correlation techniques and on-line numerical analysis in order to reject bad scans and to achieve maximum data reduction. Further software improvements might also be added using commercial software packages and software tools running under the PC-DOS operating system.

Acknowledgments

The authors would like to thank K D Krause for his help in implementing the FORTH-kernel on the Z80 slave computer system.

References

Borland International 1985, Turbo Pascal, Version 3.0 Reference Manual, 4585 Scotts Valley Drive, Scotts Valley, CA 95066, USA

Bourauel Ch, Büttgenbach S and Rupprecht W 1987 Isotope shift measurements in zirconium by Doppler-free laser polarization spectroscopy
Z.Phys. **D7** 129-32

Brenner T, Büttgenbach S, Rupprecht W and Träber F 1985 Nuclear moments of the low abundant natural isotope ^{176}Lu and hyperfine anomalies in the lutetium isotopes
Nucl.Phys. **A440** 407-23

Büttgenbach S and Küpper T 1986 A temperature-controlled non-confocal spherical mirror marker interferometer
J.Phys.E:Sci.Instrum.**19** 49-52

Büttgenbach S and Rupprecht W 1988 in preparation

Kress W 1985 Aufbau eines mikrocomputergesteuerten Messwerterfassungssystems für die Fluoreszenzspektroskopie
Diploma Thesis Universität Bonn

Laboratory Microsystems, Inc. 1984, PC/FORTH, Version 3.0 Reference Manual, P.O.Box 10430 Marina del Rey, CA 90295, USA

Figure Captions

Figure 1. Block diagram of the data acquisition system.

Figure 2. FIFO-communication between the master and the slave computer.

Figure 3. The interface box linking the data acquisition system to the spectrometer.

Figure 4. Experimental setup for laser polarization spectroscopy in a hollow cathode discharge.

Figure 5. Polarization spectrum of the transition $a^3F_2 \rightarrow z^5F_1$ of ZrI (λ = 595.5 nm).

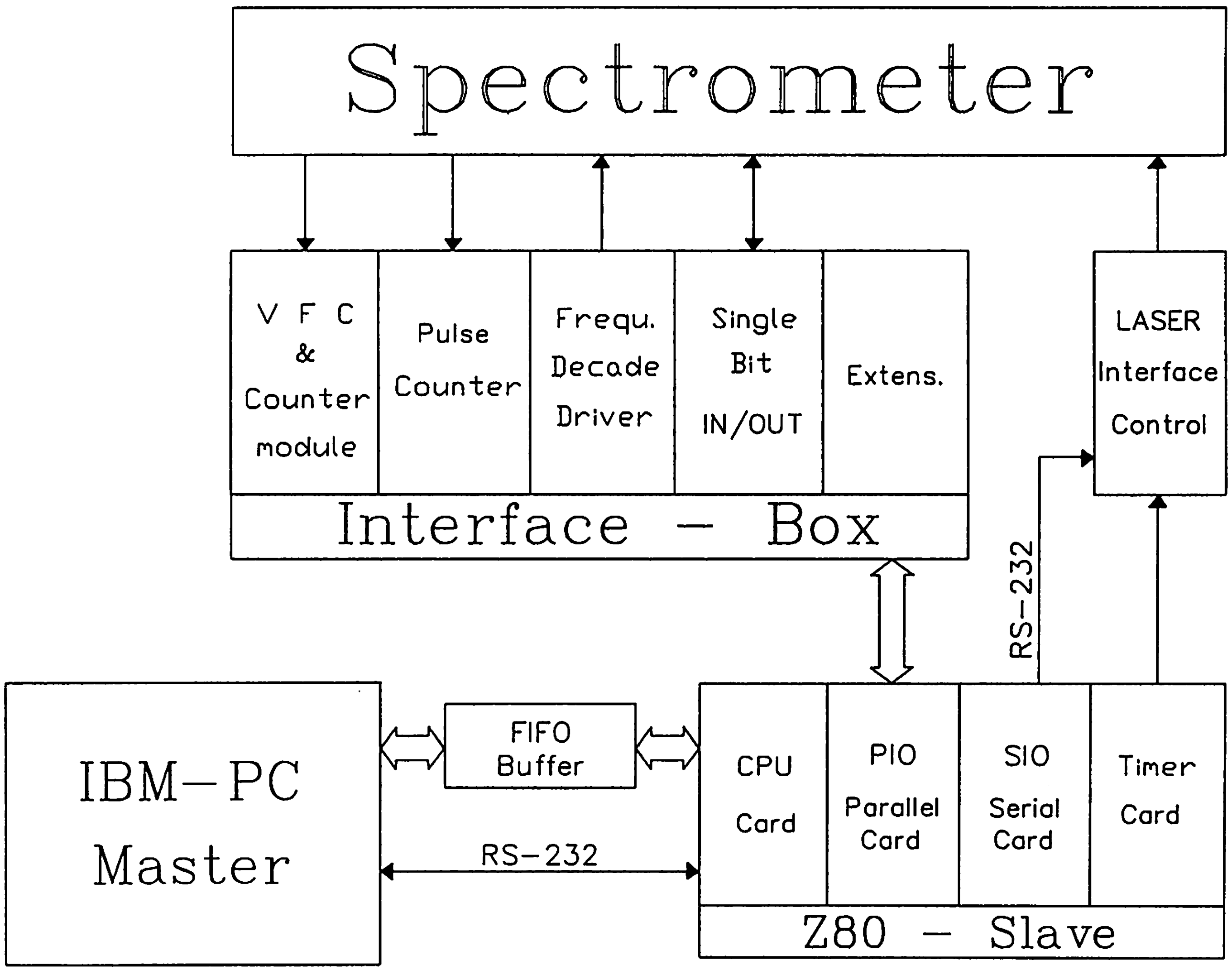

Spectrometer
V F C
&
Counter
module
Pulse
Counter
Frequ.
Decade
Driver
Single
Bit
IN/OUT
Extens.
Interface – Box
LASER
Interface
Control
RS–232
IBM–PC
Master
FIFO
Buffer
RS–232
CPU
Card
PIO
Parallel
Card
SIO
Serial
Card
Timer
Card
Z80 – Slave

Figure 1

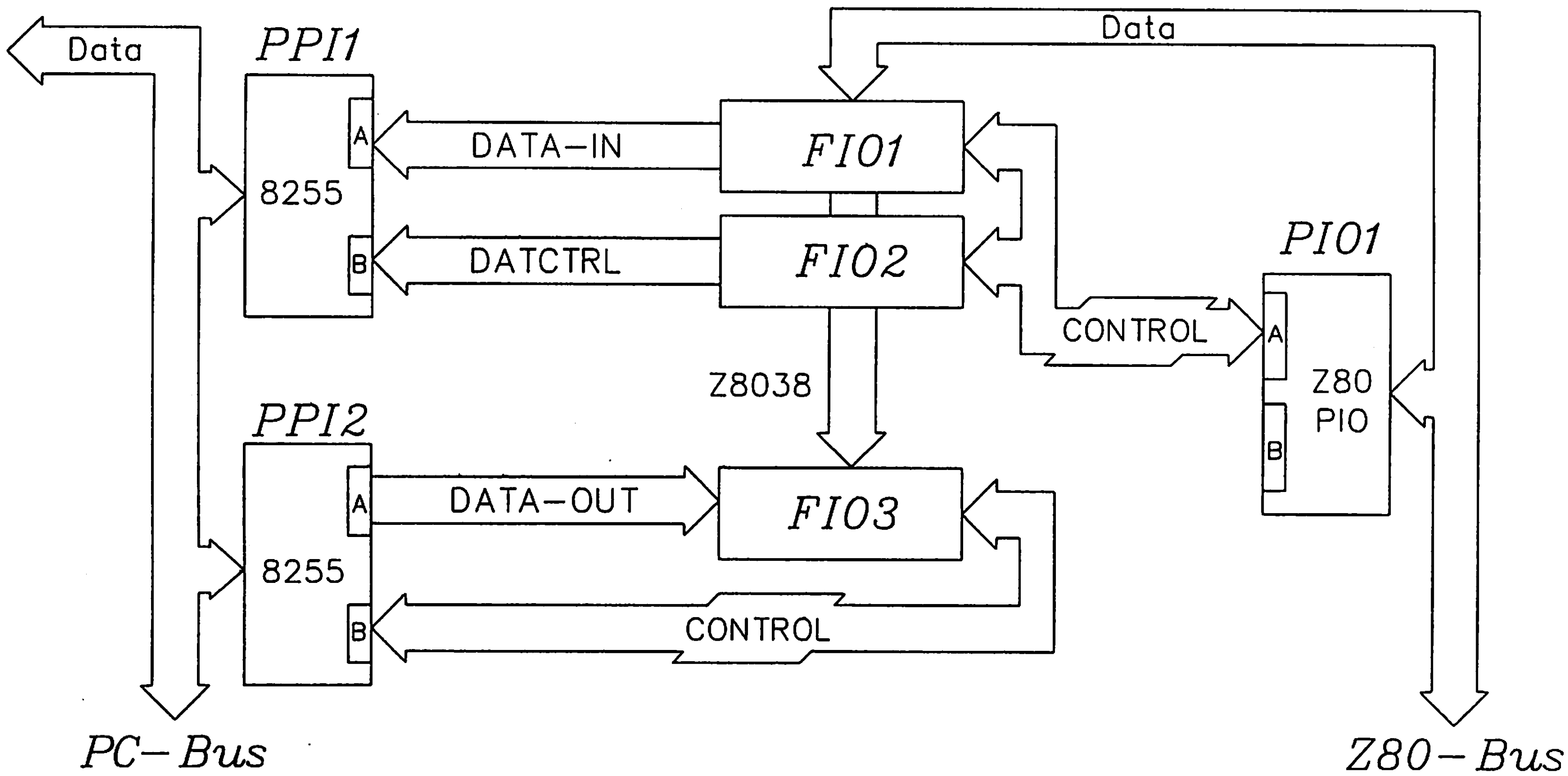
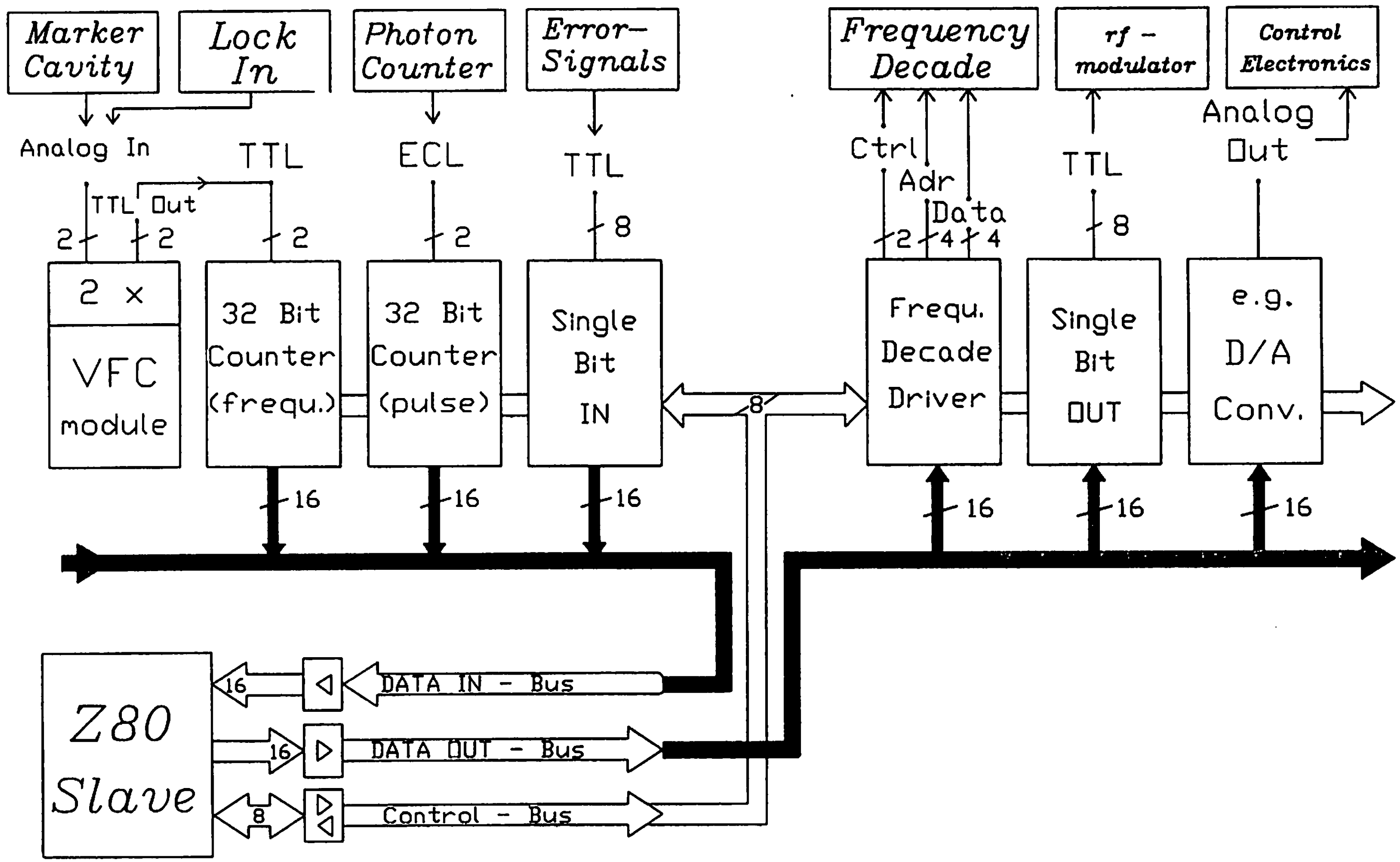

Data
PPI1
8255
A
B
DATA-IN
DATCTRL
FIO1
FIO2
Data
PIO1
CONTROL
A
Z80
PIO
B
Z8038
PPI2
8255
A
B
DATA-OUT
FIO3
CONTROL
PC-Bus
Z80-Bus

Figure 2



Marker Cavity
Lock In
Photon Counter
Error-Signals
Frequency Decade
rf - modulator
Control Electronics
Analog In
TTL
ECL
TTL
Ctrl
Adr
Data
TTL
Analog Out
TTL Out
2
2
2
2
8
2
4
4
8
2 x
VFC module
32 Bit Counter (frequ.)
32 Bit Counter (pulse)
Single Bit IN
Frequ. Decade Driver
Single Bit OUT
e.g. D/A Conv.
8
16
16
16
16
16
16
Z80 Slave
16
16
8
DATA IN - Bus
DATA OUT - Bus
Control - Bus

Figure 3

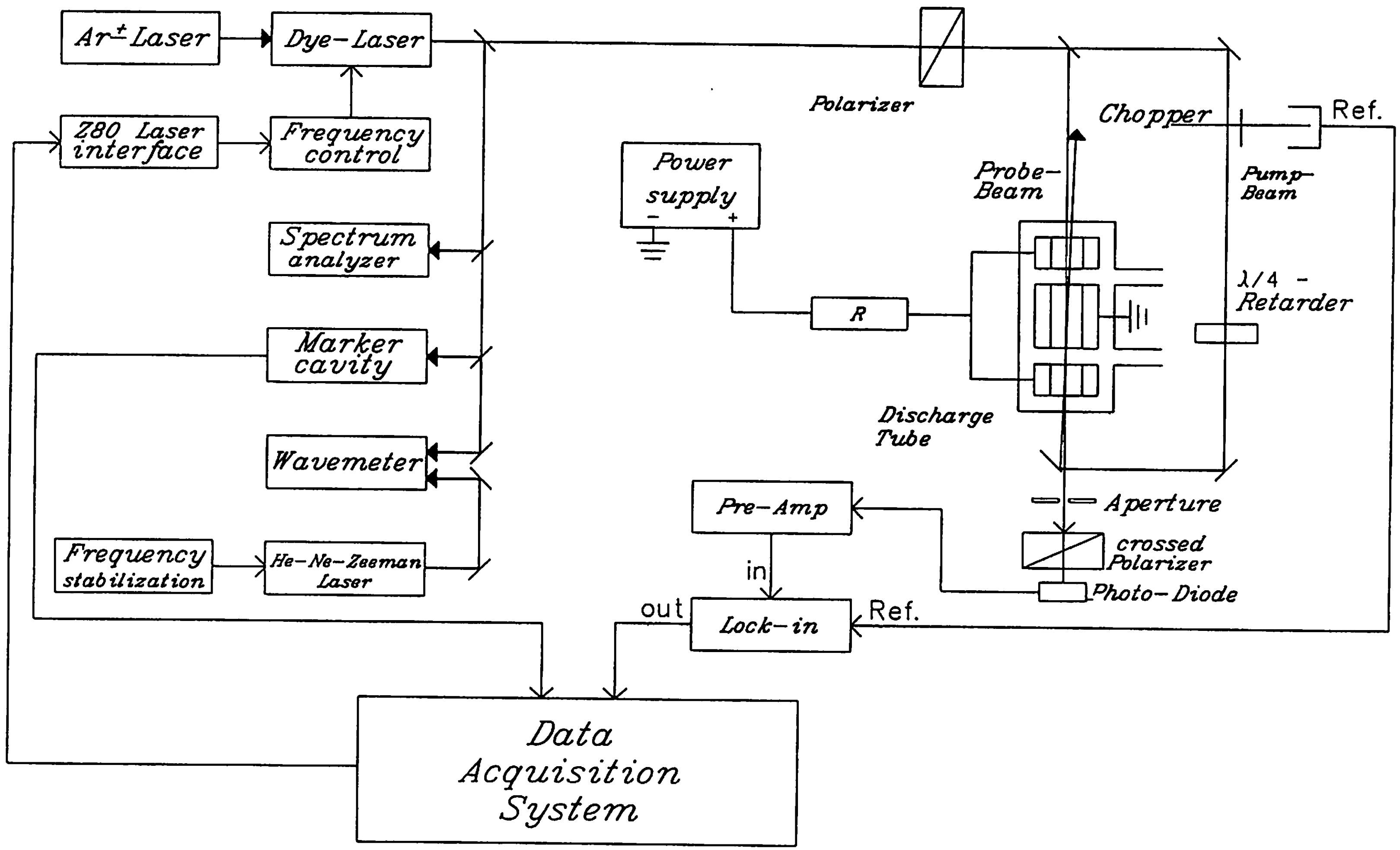

Ar+ Laser
Dye-Laser
Z80 Laser interface
Frequency control
Spectrum analyzer
Marker cavity
Wavemeter
Frequency stabilization
He-Ne-Zeeman Laser
Polarizer
Power supply
R
Chopper
Ref.
Probe-Beam
Pump-Beam
λ/4 - Retarder
Discharge Tube
Aperture
crossed Polarizer
Photo-Diode
Pre-Amp
in
out
Lock-in
Ref.
Data Acquisition System

Figure 4

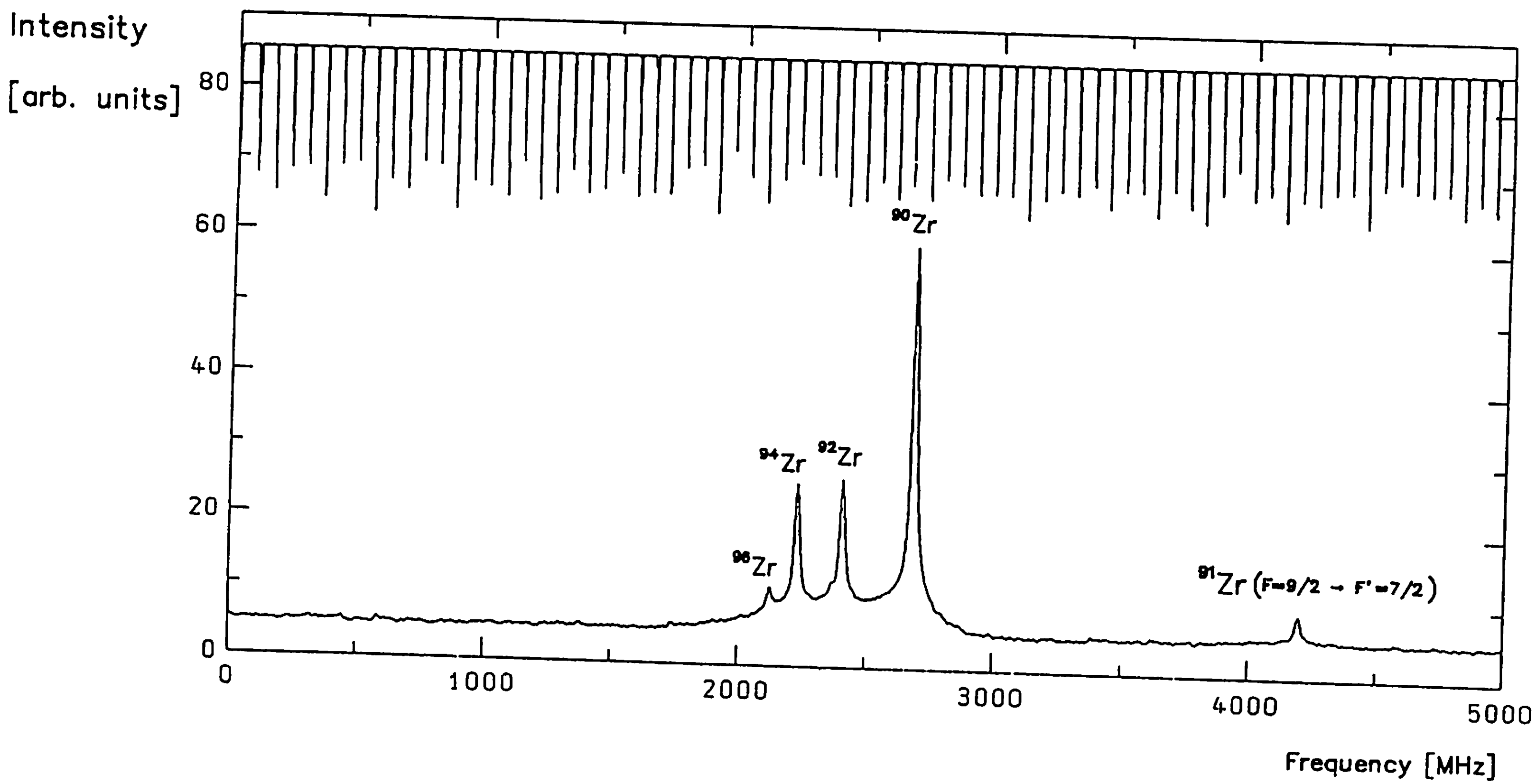

Intensity
[arb. units]
80
60
40
20
0
0
1000
2000
3000
4000
5000
Frequency [MHz]
90Zr
94Zr
92Zr
96Zr
91Zr (F=9/2 → F'=7/2)

Figure 5