

# Magnum User's Manual

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# Chapter 1

## Setting Up the Magnum

### 1.1 Installing the Data Acquisition System

The data acquisition system consists of three components: a PCI card that must be installed in a computer, a terminal board, and a cable to connect the PCI card to the terminal board. These components are each packaged separately. Begin by opening the box marked “Data Acquisition PCI Card”. This box contains an instruction manual for setting up the PCI card in your computer. Follow the instructions and install the software. Connect the terminal board to the PCI card using the cable provided and make sure the data acquisition system is functioning correctly before proceeding.

### 1.2 Setting Up the Polarization and Sensor Coils

The Magnum is designed to operate using the Earth’s magnetic field. The coils must therefore be placed in a position where there is minimal disturbance of the field. This usually means placing the coils outdoors away from any structures containing ferromagnetic materials and away from any power lines or other sources of electromagnetic interference. The coils may be operated indoors as long as it can be verified that the magnetic field is uniform. Any non-uniformity in the field will cause the performance of the instrument to be degraded.

The polarization coil is the large coil mounted on a white acrylic tiltable platform. The sensor coils are the smaller double coils that fit inside the polarization coil. Both coils have a 50 foot (15 meter) cable attached to them. The coils should be placed on a flat level surface. When placed outside, it is recommended that the coils not be put directly on the ground, since ferromagnetic rocks and other materials in the soil may cause small localized distortions of the Earth’s magnetic field.

The symmetry axis (the axis around which the coil is wound) of the polarization coil should be oriented so that it is perpendicular to the Earth’s magnetic field. In the northern hemisphere, the magnetic field enters the ground at an angle called the Magnetic Inclination. The polarization coil must therefore be tilted from the horizontal by an amount equal to the magnetic inclination angle. So to properly align the coil,

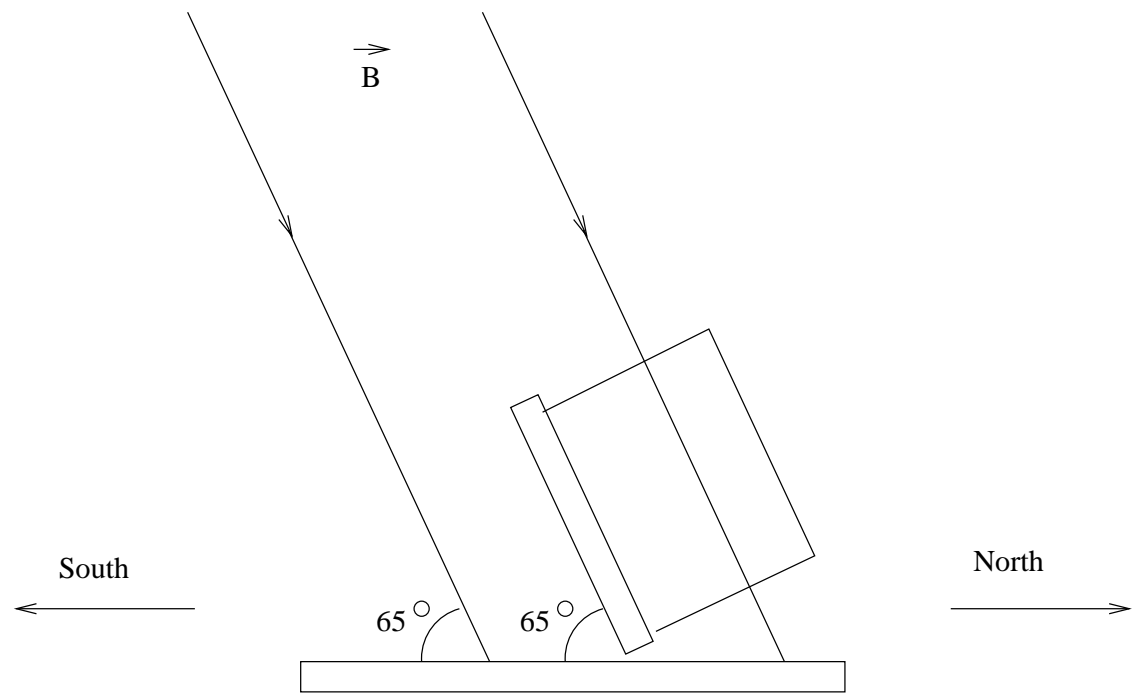


Figure 1.1: Example: Magnetic Inclination Angle and Coil Alignment in Longmont, Colorado

orient the platform on which the coil is mounted (using a standard magnetic compass), such that the axis about which the coil tilts, is perpendicular to the magnetic north direction, and tilt the coil by an amount equal to the magnetic inclination. The coil is held in the tilted position by two brass strips that slide onto rods on either side of the platform. The holes in the brass strips allow the angle to be fixed at approximately five degree increments from zero to ninety degrees.

There are many places on the Internet that provide geomagnetic data to allow magnetic inclination angle to be calculated at most locations on the Earth. For some links visit our Magnum web page: <http://www.exstrom.com/magnum.html>

As an example, the magnetic inclination angle in Longmont, Colorado is approximately 65 degrees. The polarization coil must therefore be aligned as shown in the figure below:

Once the polarization coil has been aligned correctly, place the two smaller sample coils inside the polarization coil so that the cable coming from the sample coils exits the opening of the polarization coil in either the north or south direction. The cables coming from the polarization and sample coils will be attached to the pulse switcher and the amplifier respectively as described below. It is recommended that the two cables be separated as much as is practical between their two attachment points.

### 1.3 Setting Up the Pulse Switcher

The pulse switcher is contained in a black metal enclosure with two large red binding posts for attaching the polarization coil cable, an eight position terminal block, and two LEDs on the front panel. Set the pulse switcher near the computer containing the data acquisition card. The rear panel of the pulse switcher has an RS232 connector. Connect this to any of the free serial ports on the computer using the provided RS232 cable. Not all RS232 cables may work, so it is important to use the provided cable.

Connect the included power cable to the rear panel of the switcher and plug it into a wall outlet. The power switch for the pulse switcher is located next to where the power cable is attached. At this point turn the power switch on and verify that the green LED power indicator on the front panel lights. Turn the power switch back off until you have completed the rest of the setup and are ready to operate the instrument.

Next attach the cable from the polarization coil to the two large red binding posts on the front panel. The cable from the polarization coil has two wires with fork terminals attached to the ends. One wire is attached to one of the binding posts and the other wire to the remaining post. It makes no difference which wire is attached to which post.

Connect post 7 of the terminal block on the front panel of the switcher (the posts are clearly labeled 0 to 7) to the post marked ADTGIN on the data acquisition terminal board. It is best to position the data acquisition terminal board on the side of the switcher closest to post 7. This completes the setup of the pulse switcher.

### 1.4 Setting Up the Amplifier

The amplifier is contained in a metal enclosure with a three position terminal strip on one end, a BNC connector on the opposite end, and a power connector and switch located on the side. Place the amplifier next to the data acquisition terminal board so that the board is between it and the pulse switcher.

Connect the cable from the sample coil to the three position terminal strip on the amplifier. The cable from the sample coil has three wires with fork terminals attached to the ends. One of the wires is bare with no insulation. This wire should be attached to the post marked GND on the terminal strip. The other two wires are insulated with one of them colored black and the other red. These two wires should be attached to the remaining two posts on the terminal strip. Which wire is attached to which post makes no difference.

Connect the provided coaxial cable to the BNC connector on the amplifier. The other end of the coaxial cable has two wires. One of these wires should be attached to the post marked CH0 and the other to the post marked CH1 on the data acquisition terminal board. It does not matter which wire is attached to which post.

Locate the white acrylic battery box that supplies power to the amplifier. Place the box next to the amplifier, and plug the power cord from the box into the power plug on the side of the amplifier. Make sure the power switch is in the OFF position before plugging in the power cord.

The amplifier must next be tuned so that the sample coils resonate at the frequency corresponding to your local magnetic field. To determine this frequency you need to

|                  |     |     |     |    |      |      |      |     |       |       |       |      |
|------------------|-----|-----|-----|----|------|------|------|-----|-------|-------|-------|------|
| Switch Number    | 1   | 2   | 3   | 4  | 5    | 6    | 7    | 8   | 9     | 10    | 11    | 12   |
| Capacitance [uF] | .56 | .39 | .22 | .1 | .056 | .039 | .022 | .01 | .0056 | .0039 | .0022 | .001 |

Table 1.1: Capacitances Corresponding to Switch Number in the Amplifier.

estimate the strength of your local magnetic field. To do this go to the magnum web page: <http://www.exstrom.com/magnum.html>. Once you have an estimate of the frequency, you can calculate the capacitance needed to tune the amplifier. The calculation can be done using the following formula:

$$C = \frac{a}{f^2}$$

where  $a$  is a constant that depends on the inductance of the sample coil, and is approximately 3.7. The precise value of  $a$  for your particular sample coil, should have been included with your Magnum. This formula gives capacitance in units of Farads. To select the proper capacitance you need to remove the top panel of the amplifier in order to access the 12 position dip switch located near the input of the amplifier. Each dip switch corresponds to a capacitance value as shown in table 1.1.

Turn on dip switches so that their corresponding capacitance values add up to a value as close as possible to the one you calculated above. After selecting the capacitance, place the top panel back on the amplifier.

## 1.5 Setting Up the Software

Create a directory on your computer called magnum. Copy all the files from the included disk under the subdirectory called magnum into the directory you just created. The magnum subdirectory on the disk will have a number of subdirectories under it. Make sure that these subdirectories are also copied with the same names as on the disk and make sure all of their contents have been copied.

## Chapter 2

# Using the Magnum

Once the instrument has been setup as described in the previous chapter it is ready for use. In this section we will start with a brief description of how to use the instrument. This is designed to quickly get you started with its operation. After the quick start guide, a more detailed description of the function and use of all the system components as well as the theory of operation is provided.

### 2.1 Quick Start Guide

The basic operation of the Magnum is controlled by a program called `adl`. This program is run from the command line by typing:

```
adl filename pn
```

where `filename` is the name of a parameter file and `pn` is the serial port number to which the pulse switcher is connected. A default parameter file called `adl.par` is provided. The meaning of all the parameters in this file will be discussed in detail in a later section. For now just open the parameter file in any text editor and go to the last line in the file. This line contains the name of the data file that will be produced when the Magnum is run by the program `adl`. You can accept the default value of the name or change it to whatever you want.

After you have edited the parameter file, you are ready to run the program. Before running the program however, you must turn on the power to the pulse switcher and the amplifier. Run the program and observe the red LED on the front panel of the pulse switcher. With the default parameter file, the LED should turn on for six seconds indicating that current is being applied to the polarization coil. It will then turn off for 14 seconds and repeat this process a total of 4 times. During the running of the program, diagnostic messages will also be printed out on the screen. When the program is finished running, the data file whose name you specified above will exist on your computer. This is a raw time series data file of the signal from the sensor coils. The first few lines in the file are comments indicating the parameters that were used to produce the data. The rest of the file is just time series data points that can be plotted with any plotting program. Without filtering however there will generally be too much

interference for this raw time series data to be of much use. Filtering the data and producing a spectrum is discussed in more detail below.

## 2.2 General Theory of Operation

Before discussing in detail how all the components of the Magnum operate, we will give a general description of its theory of operation.

The polarization coil is designed to produce a magnetic field that is much stronger than the Earth's magnetic field and perpendicular to it. This causes a net magnetization of the protons in the sample in the direction of the polarizing field. When the polarization field is turned off, the protons will precess about the Earth's magnetic field, inducing a voltage in the sample coil. This voltage signal is amplified, digitized, and then digitally filtered.

The current used to generate the magnetic field of the polarization coil is controlled by the pulse switcher. The pulse switcher contains a microcontroller which is programmed to turn the current in the polarization coil on and off for precise time intervals. A sequence in which the current is turned on and off for specified time intervals is referred to as a pulse. The microcontroller receives its program instructions through an RS232 serial connection to a computer.

The signal from the sample coils is fed into a high gain amplifier. The output of the amplifier is fed into the data acquisition card. It is also the job of the pulse switcher to trigger the data acquisition at the end of a pulse. Once a data file has been produced on the computer, it is filtered to remove environmental noise picked up by the sample coils.

Note that the reason there are two sample coils is to cancel out environmental noise. The two coils are wound in opposite directions with respect to each other and connected in series. They are mounted parallel to each other so that external magnetic field noise common to both coils is cancelled out. The NMR signal from the sample in one of the coils can then be detected with minimal interference. This implies that to get a signal, you must place a bottle filled with a hydrogen rich liquid into only one of the sample coils. If you were to place a filled bottle in each sample coil, then a signal would be produced in each coil, and the two signals would exactly cancel each other out, resulting in no signal at all.

## 2.3 Detailed Theory of Operation

The program `ad1` controls the overall operation of the Magnum. When run, the program first sends instructions to the microcontroller in the pulse switcher. These instructions tell it how long to turn on the current in the polarization coil and how long to wait between turning off the current and triggering the data acquisition. The program next initializes the data acquisition system according to a set of specified parameters (described below). To start a pulse, `ad1` sends the `run_program` command to the pulse switcher. The pulse switcher turns on the current in the polarization coil for the specified time and then triggers the data acquisition system (`daq`) to start taking data. When

the data acquisition is complete, `adl` will scale the data so that values reflect true voltage levels. If more than one pulse is specified then another `run_program` command is sent to the pulse switcher and the above process is repeated. The program averages the data from all the pulses and stores the result in a specified data file.

The parameters that `adl` needs to perform the setup and running of the system, as described above, are contained in a parameter file that is specified on the command line when the program is run. A default parameter file called `adl.par` is provided. The contents of this file are shown below.

```
ADAC5501 //Device name (32 char max)
D //Input type [D]ifferential or [S]ingle ended
0 //Channel number [0-7] (Diff) or [0-15] (SE)
B //Polarity [U]nipolar or [B]ipolar
1 //Gain [1,2,4,8,16,32,64]
16384 //Samples per second
65536 //Number of samples
6.0 //Pulse length in seconds [0-13]
0.1 //Daq trigger delay in seconds
4 //Number of pulses
10.0 //Pulse delay in seconds
magnum1.dat //Output file name
```

All these parameters must appear in every parameter file and they must appear in the order shown above. The values of the individual parameters may of course differ from what is shown above. The first item on each line is the value of the parameter and everything after the double slash marks is a comment. The first seven parameters are used to initialize the data acquisition system. The next four are used for initializing the pulse programmer and running the pulse sequence. The last parameter gives the name of the data file that is created when the program is finished running. The meaning of each of these parameters will be discussed in detail below.

The device name parameter only has meaning if there is more than one data acquisition card that is being used with the system. The current version of `adl` does not actually make any use of this parameter so its intent is for future use. It must however remain as the first item in the parameter file.

The input type parameter has two possible values: `D` for differential or `S` for single ended. This parameter refers to the way in which the data acquisition system treats the signals present at its input channels. With single ended inputs the voltages at all 16 input channels are digitized with respect to ground. With differential inputs what is digitized is the difference in voltage between adjacent odd and even channels. Differential inputs offer a much higher degree of noise immunity than single ended inputs. It is therefore recommended that differential inputs always be used with the Magnum.

The channel number parameter specifies the input channel of the data acquisition system that the output of the Magnum's amplifier is connected to. This is the channel that will be digitized. If you are using differential inputs (recommended) then the amplifier output should be connected to the posts marked `CH(2*n)` and `CH(2*n+1)` on the daq terminal board where `n` is the channel number that you specified. If `n` is 0 as

in the default parameter file shown above then the two wires at the end of the coaxial cable coming from the amplifier should be connected to the posts marked CH0 and CH1.

The polarity parameter can have two values: B for bipolar and U for unipolar. Unipolar means that the input voltages to the daq will always be positive. Bipolar means that the input voltages can be both positive and negative. The output voltage of the Magnum amplifier will have a DC component close to zero and will swing both positive and negative so this parameter should always be set to B for bipolar.

The data acquisition system can amplify its input signal by an amount given by the gain parameter. When the input is set to bipolar it can range between  $+10/g$  and  $-10/g$  volts where  $g$  is the specified gain. If the input is outside this range then distortion will occur. To set this parameter first run the system with a gain of 1. The maximum value of  $g$  that you should then use must be such that your data falls within the range of  $+10/g$  to  $-10/g$  volts. If the Magnum is used in a magnetically noisy environment then the gain may have to be limited to 1.

The samples per second parameter specifies the number of times per second that the daq digitizes its input signal. When digitizing any signal the samples per second must be greater than twice the highest frequency component in the signal. For most locations on the Earth the NMR frequency will not be much greater than about 3 kHz. The value of 16384 in the default parameter file should therefore be more than enough for most Earth's field NMR signals. Setting this value much smaller will however decrease your frequency resolution. Note that the value that you specify here may not be the actual value that is used by the daq but in most instances it should be very close. The actual sampling rate that is used will be placed in the header of the data file (see below) that is created when `ad1` is finished running. The actual value will also be printed out on the screen during the program's initialization of the daq.

The number of samples parameter simply gives the total number of times that the daq will digitize the signal. This is the total number of data points that will be stored in the final data file. The amount of time that this represents can be found by dividing this parameter by the samples per second parameter. For the default parameter file this is  $65536/16384=4$  seconds of data. Note however that you should use the actual sampling rate value used by the daq and not the value requested in the parameter file if you want an exact time.

The pulse length parameter gives the length of time in seconds that the current in the polarization coil is turned on. It therefore gives the length of time that the protons in the sample are subjected to the polarization field. The maximum time that can be specified is 13 seconds. Longer times do not provide any significant increase in performance and cause undue strain on the electronics of the switching circuit. The maximum time resolution of this parameter is 102.4 microseconds. This degree of resolution is more than enough for most uses of the Magnum. What this means is that there will be a difference between the times 6.0001 and 6.0002 but none between the times 6.0001 and 6.00011.

The daq trigger delay parameter specifies the amount of time between the end of the pulse and the beginning of the data acquisition. At the end of the pulse the current in the polarization coil is turned off. This induces voltages in the sample coil that will mask any NMR signal. These voltages should disappear within 100 milliseconds after

the current is turned off. The signal during this time period is of little use for NMR purposes and so it makes no sense to acquire data until these turnoff transients have settled down. The 0.1 second trigger delay time specified in the default parameter file should be long enough to insure that the transients have died down. You can experiment with longer or shorter times.

Both the pulse length and daq trigger delay parameters are converted by adl into instructions that can be interpreted by the pulse switcher microcontroller. These instructions are sent to the pulse switcher by adl. The pulse switcher stores the instructions and waits for the run\_program command from adl. It is the microcontroller in the pulse switcher that actually performs the timing of the pulse and the daq trigger delay. More information on the pulse switcher is given below.

Executing multiple pulses and averaging the data obtained from each pulse can improve the signal to noise ratio of the NMR signal. The number of pulses parameter tells adl how many pulses it should execute. Each pulse is executed using the same pulse and daq system parameters.

The pulse delay parameter specifies how long adl should wait between execution of pulses. When executing multiple pulses the switching circuit in the pulse switcher may begin to heat up. This can increase the time required to turn off the current in the polarization coil which in turn may decrease the strength of the NMR signal. Adding a delay between pulses allows the switching circuit to better dissipate the energy that it absorbs during the switching process. With a pulse delay, one complete pulse will last a period of time equal to the pulse length plus the daq trigger delay plus the data acquisition time plus the pulse delay.

The output file name is the name of the data file where adl stores the average of the data from all the pulses that it executes. This file will have several comment lines at the beginning that are collectively called the file header. The format of a typical data file is shown below.

```
#differential:Input type
#0 :Channel number
#bipolar :Polarity
#1 :Gain
#16384.000000 :Requested samples per second
#16393.442623 :Actual samples per second
#65536 :Number of samples
#0.100000 :Daq delay
#6.000000 :Pulse length
#4 :Number of pulses
#10.000000 :Pulse delay
-4.971924
-9.237061
-8.190918
-8.251953
-7.843018
-7.907715
-1.923828
```

```
5.462646
9.324951
```

The first 11 lines constitute the file header. These lines list the parameters used by `ad1` to create the data. The actual number of samples per second used by the data acquisition system is also listed. The data points follow the file header. The number of data points in the above file will be 65536 since this is the number of samples requested. The values of the data points represent the actual voltage levels of the signal.

We will now describe in detail the operation of the pulse switcher (PS). The back panel of the PS has a plug for an AC power cord, a power switch and an RS232 connector. The front panel has two LED indicators. The green LED lights when the power to the PS is turned on. The red LED lights when the current to the polarization coil is turned on. The front panel also has two large red binding posts for connecting the cable to the polarization coil and an eight position terminal strip. The eight position terminal strip are the digital output lines of the microcontroller in the PS. The microcontroller can be programmed to set these lines high or low (TTL levels) for precisely timed intervals. Line 0 is internally connected to the current switching circuit of the PS. A high on this line means the current to the polarization coils is turned off. When the line goes low the current is turned on. This line provides an electrical means of monitoring the turn on and turn off times of the polarization current. One of the other lines must be used to trigger the data acquisition. By default the `ad1` program instructs the microcontroller to use line 7 to trigger the daq. Only two lines, 0 and 7, are used during normal operation of the magnum. All lines are however fully programmable. This allows for future expansion of the capabilities of the Magnum to do things such as spin echo experiments. An example program called `mc` shows how to fully program the PS microcontroller to use all of its output lines. For more detailed information on this, see the magnum web page.

## 2.4 Controlling the Outputs of the Switcher

This section describes how to control the outputs of the switcher. The information in this section is not necessary for running the Magnum, but you may find it useful to have access to and control over all eight outputs on the front of the switcher.

The example program `mc.c` in the `prog` subdirectory of the `magnum` directory shows how you can program the switcher outputs. In `mc.c` you will find the five commands that the switcher recognizes:

- Set Program
- Get Program
- Run Program
- Loop Program
- Stop Program

The program for the switcher is specified as a series of states. The maximum number of states is 10. Each state is specified by 3 bytes. The binary representation of the value of the first byte gives the state of the output lines. For example if the byte equals 5, then lines 2 and 0 will be low, and all other lines high. If the byte equals 255 then all 8 lines will be low. Notice that the binary state 1 sets the output low. Also note that output line 0 is connected to an LED on the switcher chassis, which lights up when the output is set low. The next two bytes are used to specify the amount of time that the state is active. The value is calculated using the following formula:

$$65536 - \text{int}\left(\frac{10^7 * t}{1024}\right)$$

where  $t$  equals time in units of seconds and has the range:  $102.4\mu\text{sec} \leq t \leq 6.7\text{sec}$ , and  $\text{int}()$  means the integer part of the argument.

To program the microcontroller for two states, you first have to send it the Set Program command, followed by one byte which specifies the number of states, in this case “2”. Then the next byte will be the value of the first state. The next two bytes will be the time of the first state, with the lower order byte sent first, then the higher order byte. Then the next byte will be the value of the next state, followed by two more bytes which are the values of the time for the next state. Once you’ve programmed it, you can verify that its been programmed correctly by sending it the Get Program command, which will just return the information in the same order that you sent it. The file `mc.par`, which should be in the same directory as `mc.c`, is an example program. Here is a listing of an `mc.par` file:

```
4
0
6.0
1
0.5
0
6.0
1
0.5
```

The first line of the file above specifies the number of states, in this case “4”. The next line specifies the value of the first state “0”, which will set all 8 outputs low. The next line specifies the time that the first state will be on, “6.0” seconds. The next line specifies the value of the second state “1” which will set the first output high, and keep all remaining outputs low. The next line specifies the time of the second state to be “0.5” seconds. The remaining two states and their times are identical to the first two states. You can try this by starting program `mc`, running Set Program which asks for the program file name (`mc.par`), then choosing Run Program. In this case you would see the LED, that is connected to the first output, turn on for 6.0 seconds, then turn off for 0.5 seconds, then repeat once more. To see it run continuously, you can choose Loop Program, and then Stop Program when you are finished.

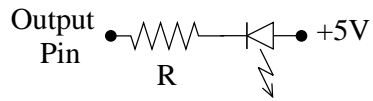


Figure 2.1: Simple way to drive LED with output pin.

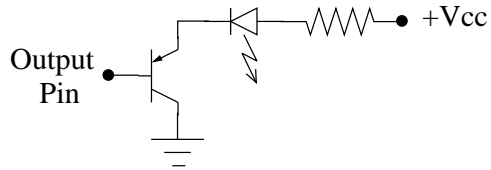


Figure 2.2: Better way to drive LED or other load.

Remember that output line 0 (the first output line) is internally connected to the current switch. You probably want to disconnect the polarizing coil from the switcher when running the example `mc.par` program listed above.

The output pins will sink 20 mA and can drive LED's directly as in figure 2.1. Choose R to limit the current to less than 20 mA.

A better way to drive an LED or some other load is shown in figure 2.2.

## Chapter 3

# Software and Data Processing

There are four programs included on the disk: `adl`, `fft`, `extract`, and `mc`. The program `adl` is used to operate the Magnum. The program is run from the command line as follows:

```
adl filename pn
```

where `filename` is the name of a parameter file, and `pn` is the serial port number that the pulse switcher is connected to. The program is discussed in detail in the previous sections.

The `fft` program computes a fast Fourier transform (FFT) of a data file. The program is run from the command line as follows:

```
fft sp np infile outfile
```

where `sp` is the starting data point and `np` is the number of data points included in the FFT. The value of `np` must be a power of 2. The `infile` and `outfile` parameters are the names of the input data file and the output FFT file.

The program `extract` is used to extract the real or imaginary parts of an FFT or the magnitude or the phase. The program is run from the command line as follows:

```
extract x infile np outfile
```

The parameter `x` can take on the values: `m`, `p`, `r`, `i`. For `x = m` the program will extract the magnitude of an FFT file. For `x = p` the program will extract the phase of an FFT file. For `x = r` the program will extract the real part of an FFT file. For `x = i` the program will extract the imaginary part of an FFT file. The parameter `infile` is the name of the input FFT file. The parameter `np` is the number of points to use in the FFT file. The parameter `outfile` is the name of the output file.

The program `mc` is an example program that demonstrates how to fully program digital output lines of the pulse switcher. It is run from the command line as follows:

```
mc pn
```

where `pn` is the serial port number that the pulse switcher is connected to. For more information on this program see Section 2.4.

For more data processing software, including digital filtering software see the Magnum website.