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A Data Acquisition System for Antenna Array Gain Characterization

by Michael L Don, John M Zajicek, Rex A Hall, and Jonathan M Hallameyer

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14. ABSTRACT

This technical note describes the design and software development of a system to characterize the gain patterns of antenna arrays. A multi-axis positioner and data acquisition are controlled using a LabVIEW program to record the amplitudes of the antenna elements over a range of azimuth and elevation angles. Example results postprocessed in MATLAB are presented to demonstrate the successful operation of the system. This system will be a valuable tool in the design and evaluation of antenna arrays for amplitude comparison applications.

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1. Introduction

The US Army Combat Capabilities Development Command Army Research Laboratory has a long history of antenna design and measurement.[1–7] In particular, DEVCOM Army Research Laboratory's Guidance Technologies Branch (GTB) developed a custom antenna-measurement system to characterize telemetry and GPS antennas for guided munitions (Fig. 1). This system used two rotary stages to rotate the antenna under test (AUT) in azimuth and elevation while measuring gain and phase response with a network analyzer. More recently, GTB has explored RF direction finding via phase interferometry as a localization technology for swarm localization.[8,9] The network analyzer was replaced by a two-port software-defined radio to measure the phase difference between two antennas' elements. However, as the number of antenna elements increase, the overhead of the phase comparison circuitry can become extremely burdensome. A simpler, though less accurate alternative is amplitude comparison direction finding.[10–12] Each channel can now be measured with an RF detector and a standard data acquisition system (DAQ). In addition, the old rotary actuators were upgraded to an ETS-Lindgren multi-axis positioning system that required new control programming.[13] This technical note describes the design and software development of this measurement system. Examples of successful operation are presented, demonstrating that it will be a valuable tool for design and evaluation of antenna arrays.

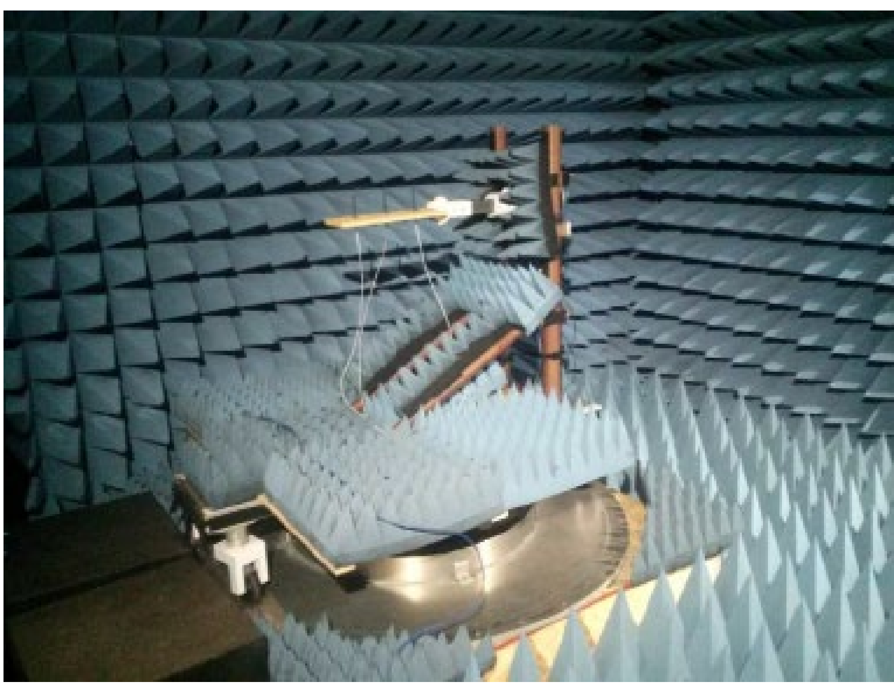

Fig. 1 GTB's antenna measurement system using a custom-designed two-stage rotation platform

2. System Overview

Figure 2 shows a diagram of the antenna array measurement system. An RF signal generator transmits the frequency of interest through the transmit (TX) antenna to the AUT. The AUT is placed on a multi-axis positioner, allowing the AUT to be characterized across a range of azimuth and elevation angles. RF detectors convert the received signal from the antenna array elements to a DC voltage, which is measured using a DAQ. A computer and positioner controller are placed in a control room outside of the anechoic chamber. The computer is connected to the positioner controller through a General Purpose Interface Bus, while the DAQ is controlled through a USB. The positioning system is an ETS-Lindgren 2010 multi-axis positioning system, composed of a 2188 turntable for rotation in azimuth, a light duty tower for rotation in elevation, and a 2090-series multi-device controller that interfaces with the positioner through optical fiber. Figure 3 shows images of the TX and receive sides of the system in the anechoic chamber.

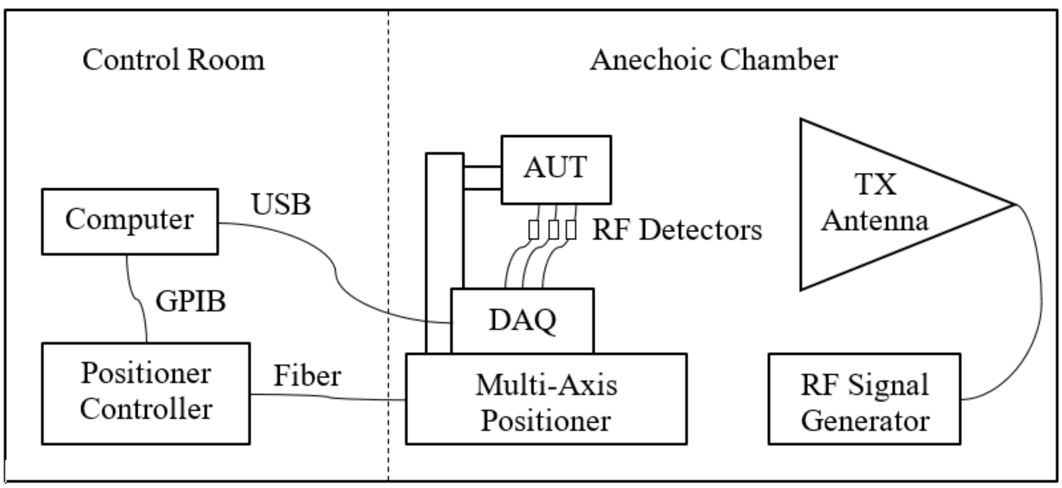

Fig. 2 System diagram

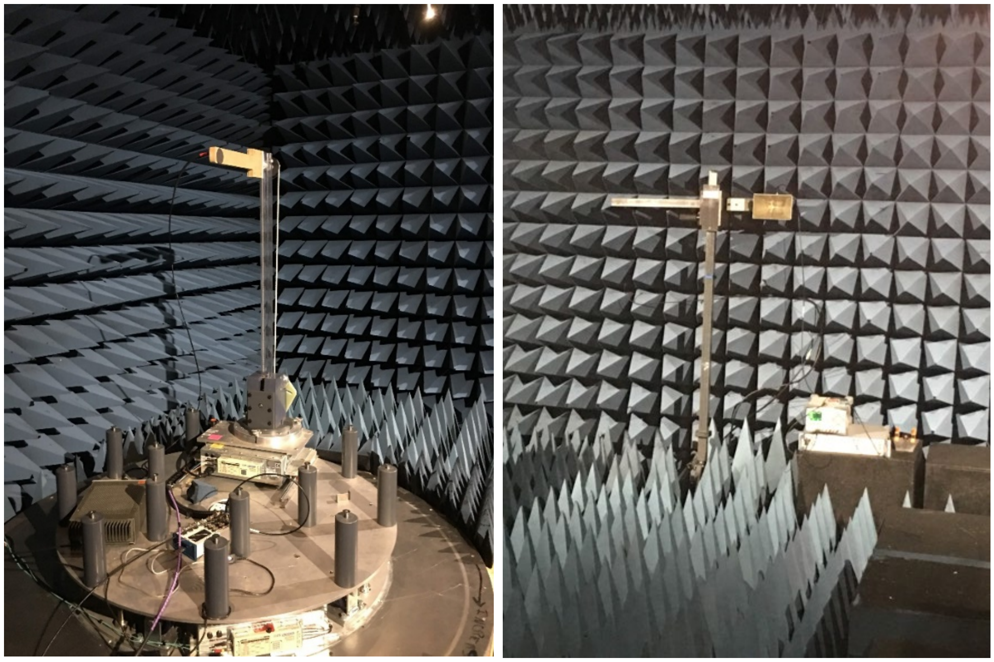

Fig. 3 (left) Receive side and (right) transmit side of the measurement system in the anechoic chamber

3. Software Design

The control software shown in Appendix A was written in LabVIEW. The program assumes the azimuth and elevation orientation shown in Fig. 4. The positioner itself has an arbitrary, but fixed real orientation. Therefore, it is necessary to input the positioner's real orientation into the `az zero` and `el zero` program controls. The program uses these variables to align the positioner to the orientation in Fig. 4. The program is designed to record up to four channels, although additional channels can be easily added.

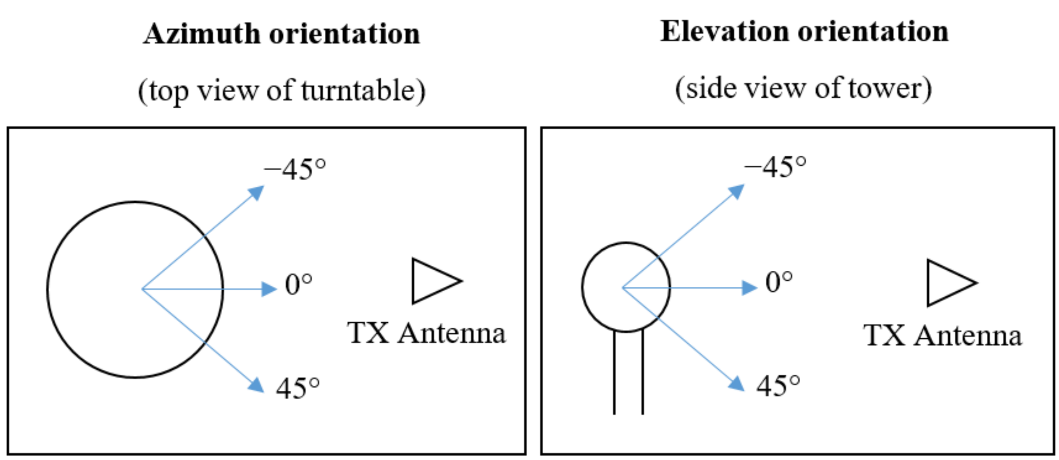

Fig. 4 Positioner rotation orientation

The program is broken into four states summarized in Table 1. In Appendix A, Fig. A-1 shows State 0. The state machine is constructed using an outer while loop and inner case statement. Four shift registers pass information between the states. Starting at the top, these registers are 1) state number, 2) current azimuth position, 3) current elevation position, 4) error cluster, and 5) recorded data. The positioner controller is actually two instruments: the turntable controller for rotation in azimuth and the tower controller for rotation in elevation. In State 0, each controller is queried to confirm a valid connection, the current position is read, and the clockwise and counterclockwise rotation limits are confirmed. The positioner is then moved to the initial position. State 1 (Fig. A-2) steps through the azimuth angles, takes multiple voltage measurements of each channel, and records the average value for each channel along with the azimuth and elevation positions. When a full azimuth sweep is completed, the state machine transitions to State 2 (Fig. A-3), incrementing the elevation. Each azimuth sweep alternates direction so that the sweep can begin immediately after the elevation increment. When all of the measurements are completed, State 3 is entered and the data is saved (Fig. A-4). Six files are created for the elevation values, azimuth values, and four channel voltages. It is important to record the actual elevation and azimuth angles, as these may be slightly different than the desired programmed values due to positioner inaccuracies.

Table 1 Control program states

State	Summary
0	Initialize positioner and variables
1	Sweep in azimuth and record voltages
2	Increment elevation
3	Save data in multiple files

Figure A-5 shows a basic display of the program's front panel. Once the positioner and DAQ settings are stored, it is simple to run the program by specifying start, stop, and increment values for azimuth and elevation, as well as the save file name. To make a 1-D sweep in azimuth or elevation, the start and stop of the elevation or azimuth, respectively, are set to the same value.

4. Example Results

Figure 5 shows example 1-D slices in azimuth from −25° to 25° in 0.5° steps for four antenna elements. Figure 6 shows an example 2-D pattern spanning −45° to 45° in 5° steps in both azimuth and elevation for one antenna element. The MATLAB script in Appendix B was used to generate the plots in Figs. 5 and 6 from data files saved using the LabVIEW control program.

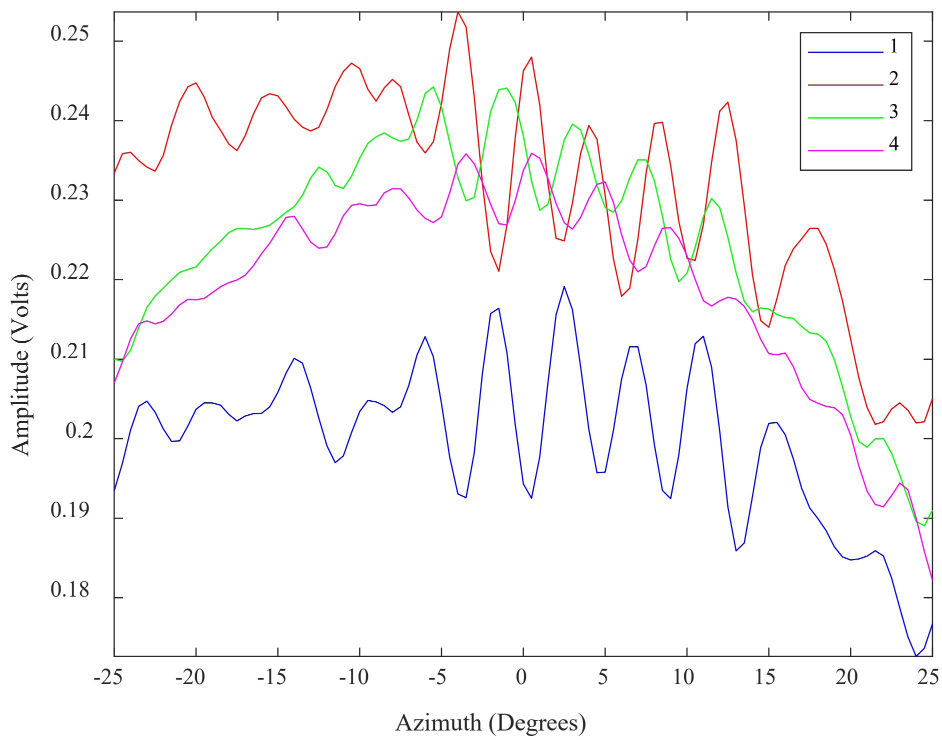

Fig. 5 Example azimuth slices of four antenna elements

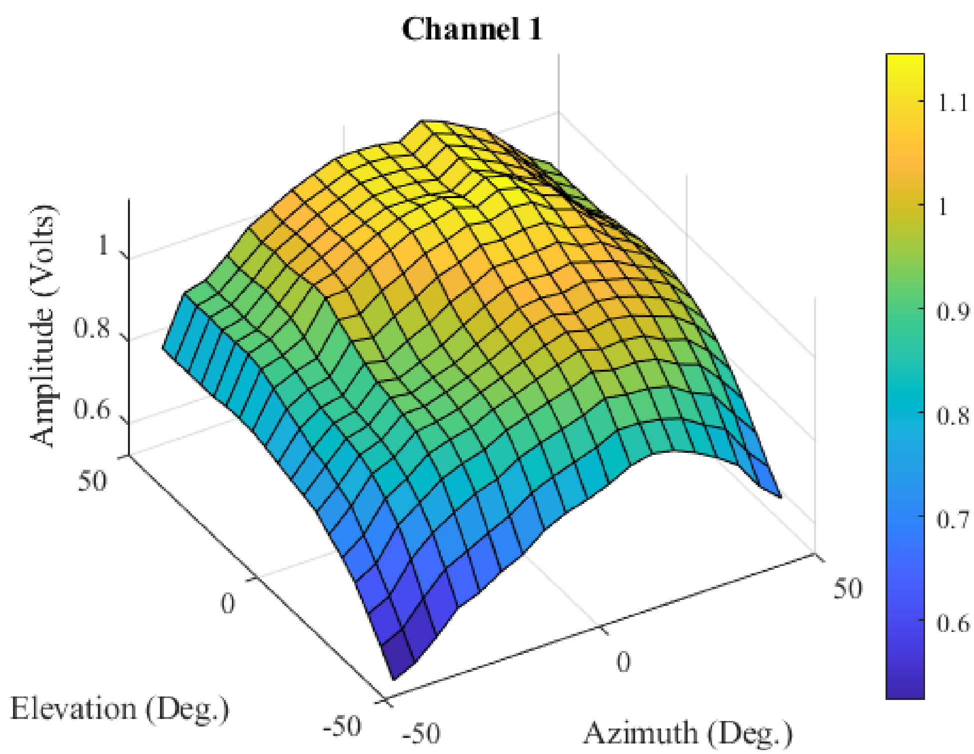

Fig. 6 Example 2-D amplitude pattern of a single element

5. Conclusion

This technical note describes the design and software development of a system to characterize the gain patterns of antenna arrays. A multi-axis positioner and DAQ are controlled using a LabVIEW program to record the amplitudes of the antenna elements over a range of azimuth and elevation angles. Example results postprocessed in MATLAB were presented to demonstrate the system's successful operation. This system will be a valuable tool in the design and evaluation of antenna arrays for amplitude comparison applications.

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Appendix A. Controller Program

The controller program was written in LabVIEW and controls the multi-axis positioner and data acquisition system to record voltages from multiple antenna elements across a range of azimuth and elevation angles (Figs. A-1 through A-5).

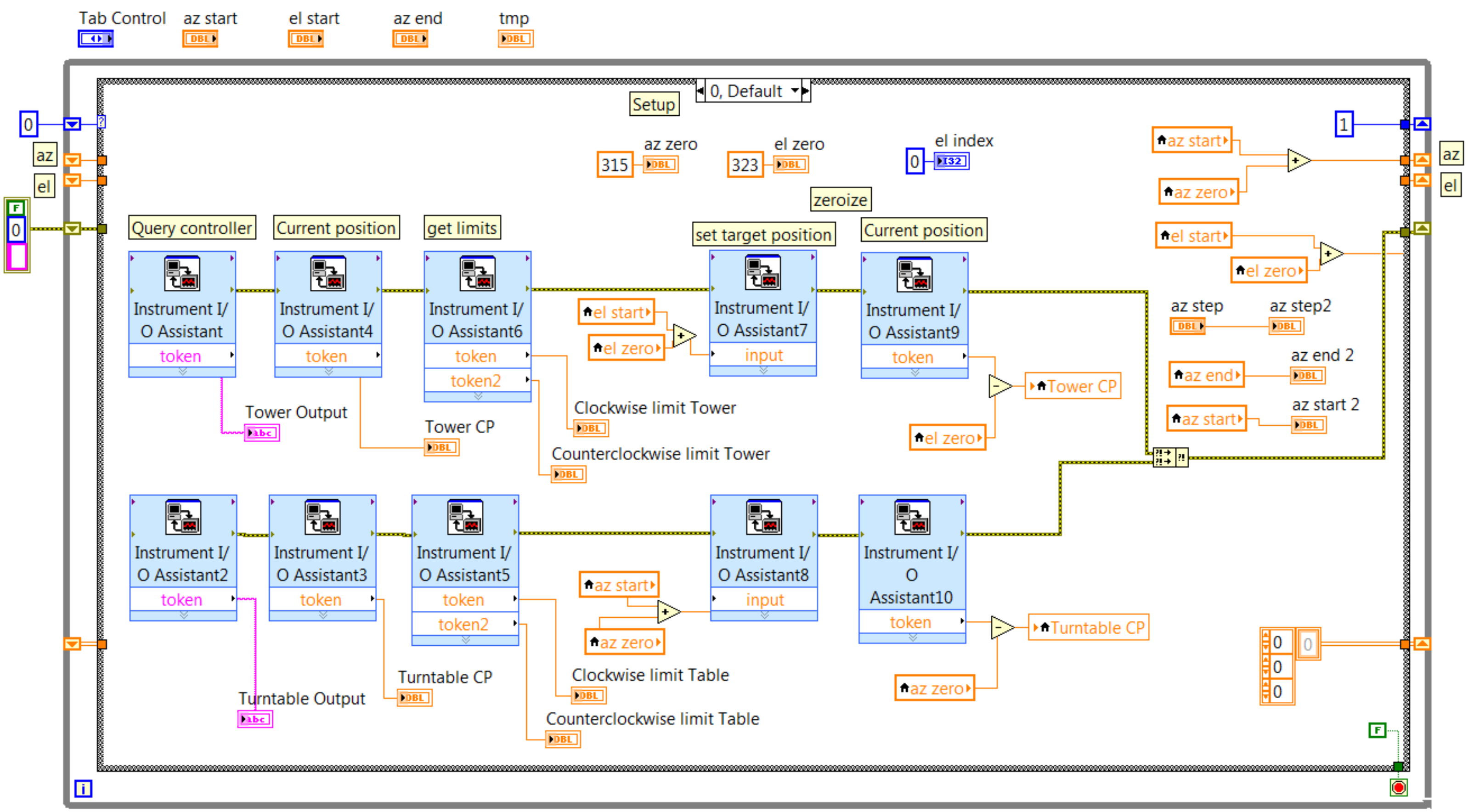

Fig. A-1 State 0 of the controller program, where the positioner and variables are initialized

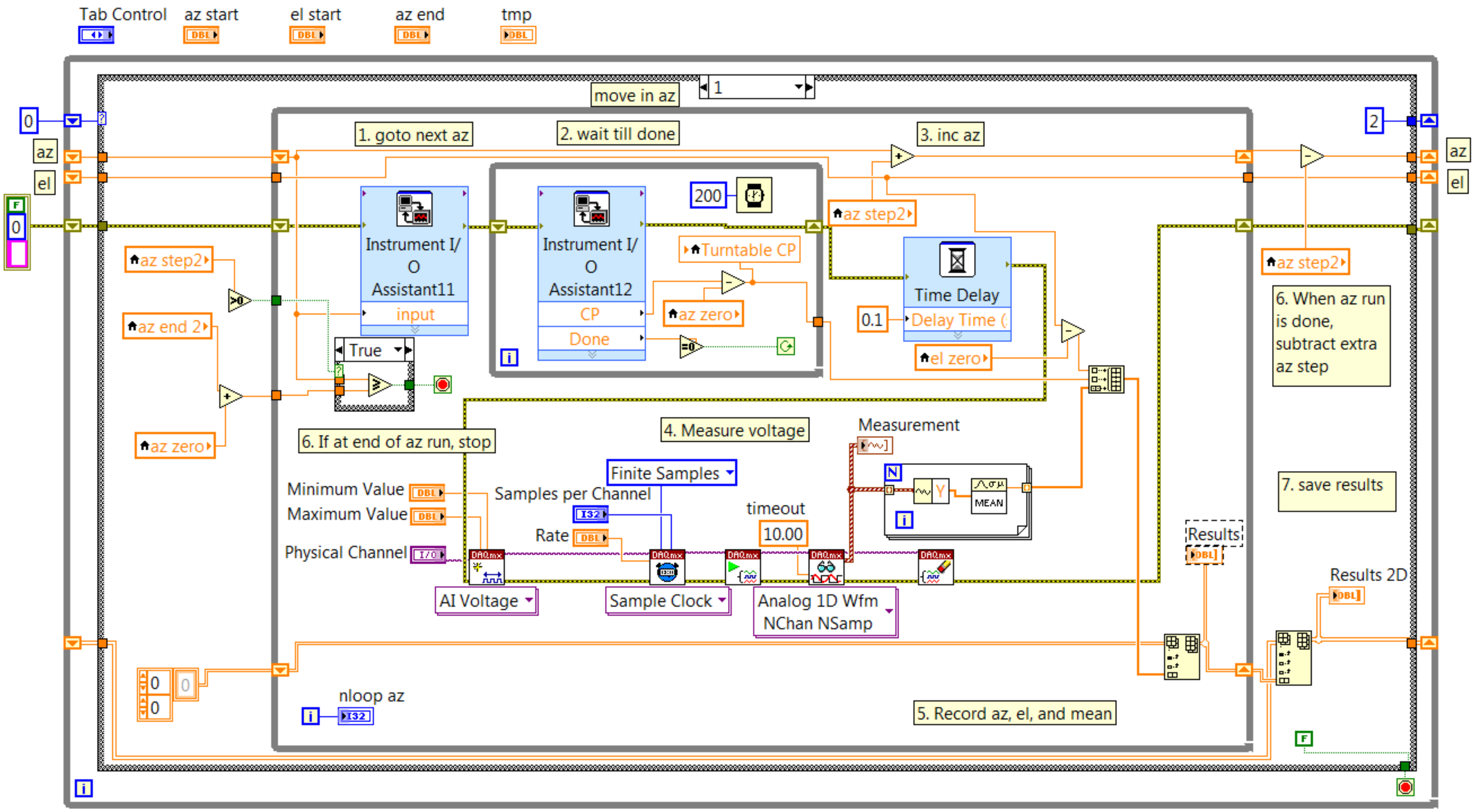

Fig. A-2 State 1 of the controller program, where measurements are made across a range of azimuth angles

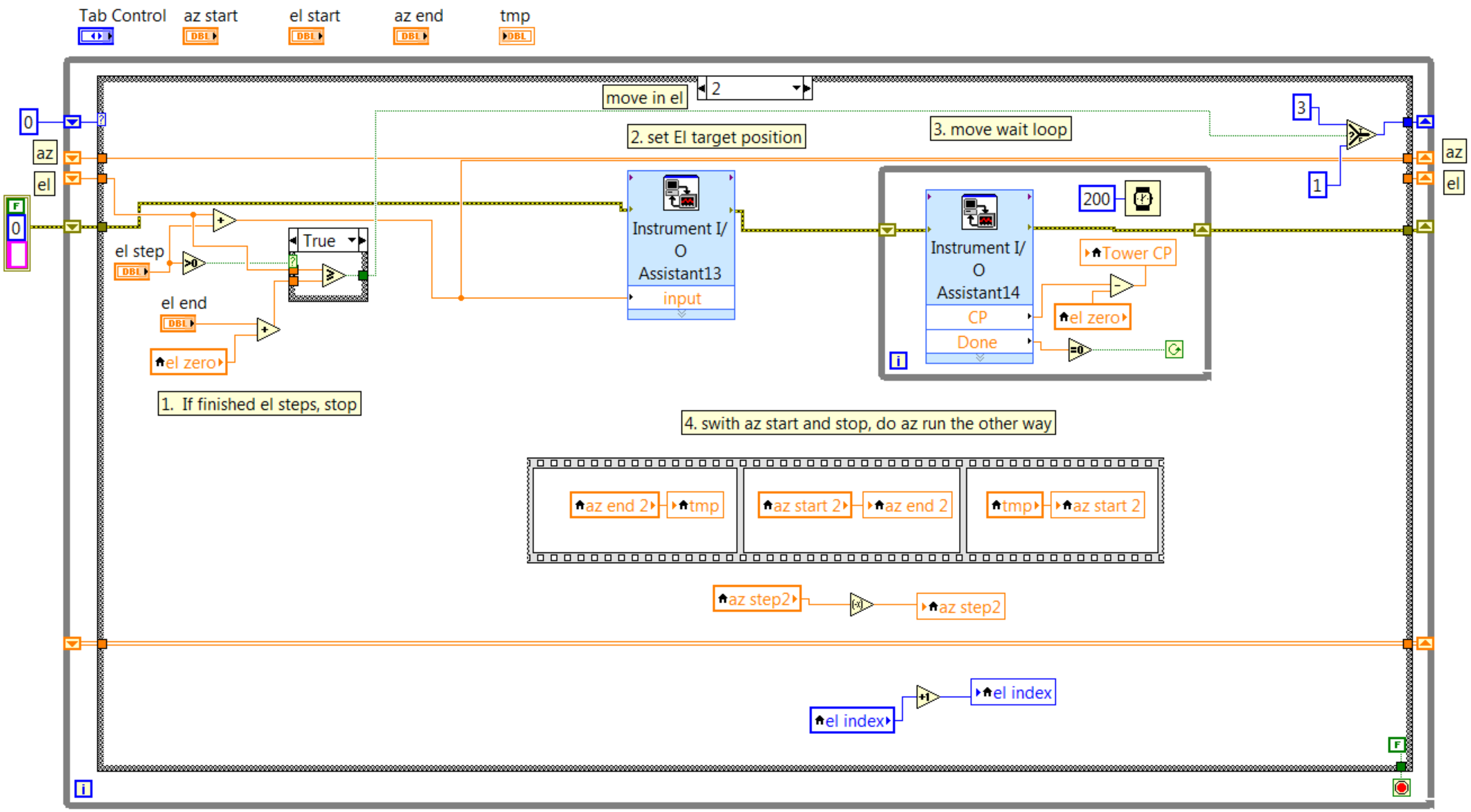

Fig. A-3 State 2 of the controller program, where the elevation is incremented

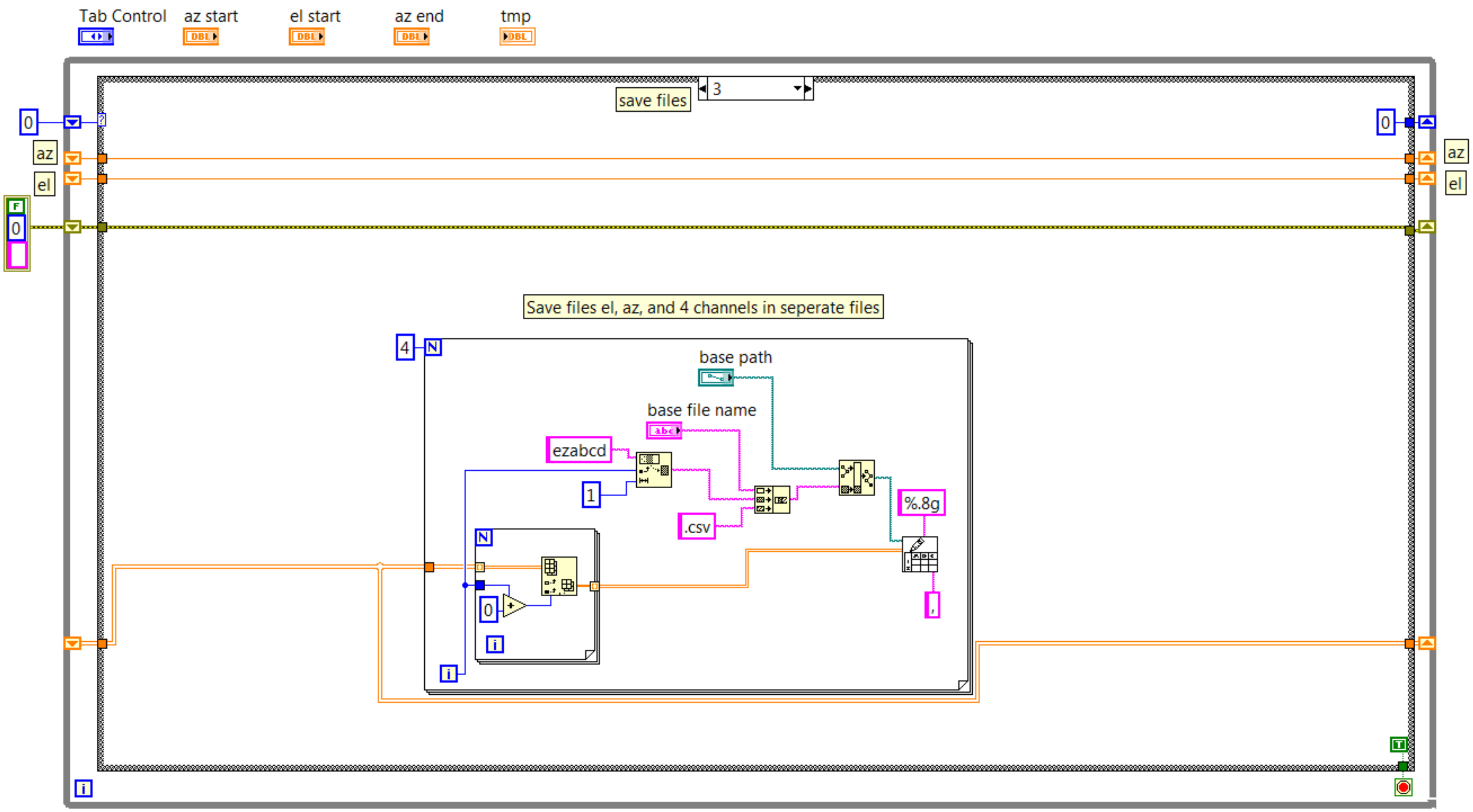

Fig. A-4 State 3 of the controller program, where the data is saved in multiple files

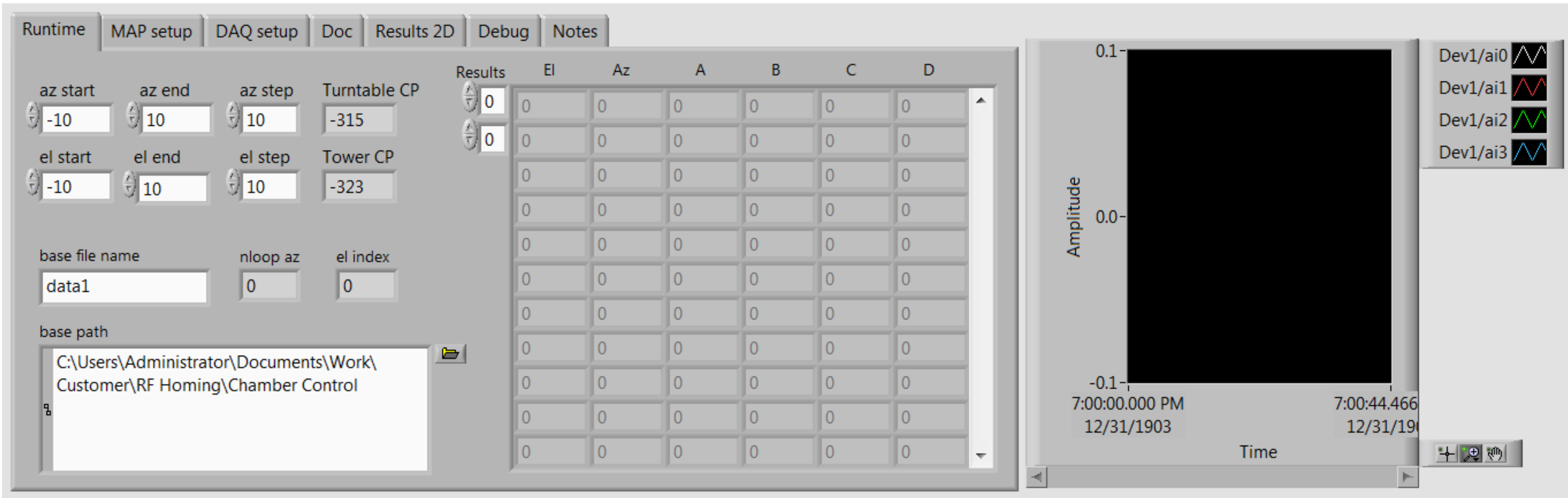

Fig. A-5 Front diagram of the LabVIEW controller program

Appendix B. Postprocessing Program

The MATLAB postprocessing program reads the data files saved by the controller program, processes the data, and plots the antenna element gain patterns.

```
clear
close all

set(0,'defaultAxesFontName','Times')
set(0,'defaultTextFontName','Times')
set(0,'defaultTextFontSize',12)
set(0,'defaultAxesFontSize',12)

%plot data
base_name='test3';
run_name='_Run0_';
dir_name = '.\Data folder\new adapter\';
a=csvread([dir_name base_name run_name 'a.csv']);
b=csvread([dir_name base_name run_name 'b.csv']);
c=csvread([dir_name base_name run_name 'c.csv']);
d=csvread([dir_name base_name run_name 'd.csv']);
e=csvread([dir_name base_name run_name 'e.csv']); %el
z=csvread([dir_name base_name run_name 'z.csv']); %az
% starts -az to +az, then +az to -az, have to reorder data
z(2:2:end,:)=z(2:2:end,end:-1:1);
e(2:2:end,:)=e(2:2:end,end:-1:1);
a(2:2:end,:)=a(2:2:end,end:-1:1);
b(2:2:end,:)=b(2:2:end,end:-1:1);
c(2:2:end,:)=c(2:2:end,end:-1:1);
d(2:2:end,:)=d(2:2:end,end:-1:1);

[nr,nc]=size(z);
figure
if nr==1 % az slice is row vector
    plot(z,a,'b')
    hold on
    plot(z,b,'r')
    plot(z,c,'g')
    plot(z,d,'m')
    axis tight
    legend('A','B','C','D')
    ylabel('Amplitude (Volts)')
    xlabel('Azimuth (Degrees)')
elseif nc==1 % el slice is col vector
    plot(e,a,'b')
    hold on
    plot(e,b,'r')
    plot(e,c,'g')
    plot(e,d,'m')
    axis tight
    legend('A','B','C','D')
    ylabel('Amplitude (Volts)')
    xlabel('Elevation (Degrees)')
else %az and el
    surf(z,e,a); title('Channel A')
    colorbar
    xlabel('Azimuth (Deg.)')
```

```
    ylabel('Elevation (Deg.)')
    zlabel('Amplitude (Volts)')
    axis tight

    figure
    surf(z,e,b)
    title('Channel B')
    colorbar
    xlabel('Azimuth (Deg.)')
    ylabel('Elevation (Deg.)')
    zlabel('Amplitude (Volts)')
    axis tight

    figure
    surf(z,e,c)
    title('Channel C')
    colorbar
    xlabel('Azimuth (Deg.)')
    ylabel('Elevation (Deg.)')
    zlabel('Amplitude (Volts)')
    axis tight
    subplot(2,2,4)

    figure
    title('Channel D')
    colorbar
    xlabel('Azimuth (Deg.)')
    ylabel('Elevation (Deg.)')
    zlabel('Amplitude (Volts)')
    axis tight
end
```

List of Symbols, Abbreviations, and Acronyms

1-D	one-dimensional
2-D	two-dimensional
AUT	antenna under test
DAQ	data acquisition system
DC	direct current
GPIB	general purpose interface bus
GPS	Global Positioning System
GTB	Guidance Technologies Branch
RF	radio frequency
TX	transmit
USB	Universal Serial Bus

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