i5.M APPENDIX: STABILITY PLOTS USING MATLAB

MATLAB programs, or "scripts," usually carry a `.m` extension to identify them to the MATLAB application, which executes them. Some scripts are shown in the text, for convenience, but they are all available for downloading. They can be read using MATLAB but, since they are text files, they can also be read by other programs, such as word processors. The `.m` extension is not used in this book but script names and content are distinguished by the use of a `distinctive font`.

All of the stability plots in Chapter 5 can easily be generated using MATLAB. In each case the open-loop transfer function is represented by a vector `NUM` consisting of the coefficients of its numerator and a vector `DEN` consisting of coefficients of its denominator. For example, the file `Bd2ordT1` produces a bode plot for a second-order type-1 loop with the open loop transfer function given by Eq. (4.2), which can be written

$$G(s) = \frac{s\dfrac{K}{\omega_z} + K}{\dfrac{s^2}{\omega_p} + s} . \tag{5.M.1}$$

The MATLAB representation is

```
NUM = [K/Wz  K] ;            (5.M.2)

DEN = [1/Wp  1  0] .         (5.M.3)
```

As can be seen from this example, the rightmost element of the vector is the coefficient of s^0, the next element is the coefficient of s^1, and so forth.

Here is the script, `Bd2ordT1:`

```
%Bode Plot from open-loop equation
% Second-Order, Type 1 (Lag-lead filter)
% Modify pole, zero, K from Eq. (5.M.1)

clf;
Wz = 1000;
Wp = .1;
K = 1000000;

num = [K/Wz K];
den = [1/Wp 1 0];
bode(num,den);
```

Run this script and select, for example, Edit/Axes Properties ... from the menu associated with the figure window to get an interesting frequency range or draw grids.

Individual files for various plots are available for downloading and we can easily change their parameters in order to observe their effects on the stability plots. You can go through Bode, Evans, and Nyquist scripts and observe the effects of modifying the parameters. Note the simplicity of these scripts (programs):

`Bd1ord.m`, Bode plot for 1st-order loop;
`Bd2ordT1.m`, Bode plot for 2nd-order type1 loop;
`Bd2ordT2.m`, Bode plot for 2nd-order type 2 loop;
`Bd3ordT2.m`, Bode plot for 3rd-order type 2 loop;
`Ev2ordT1.m`, Evans plot for 2nd-order type 1 loop;
`Ev3ordT1.m`, Evans plot for 3rd-order type 1 loop;
`NqLagLd.m`, Nyquist plot for loop with lag-lead filter;
`NqLowP.m`, Nyquist plot for loop with low-pass filter.

The Nyquist plots in MATLAB are done only for real frequencies, just the $j\omega$-axis in Fig. 5.3(a), so we can expect to be missing the corresponding parts of the plot (e.g., $p1$ to $p2$). Also, the standard `Nyquist` function draws arrows in the direction of increasing frequency on the upper and lower halves of the plot and shows a cross mark at ($-j + 0$).

One file, `ChsPlot` allows various loop configurations and various stability plots to be chosen dynamically, that is without re-executing the file. It is designed to permit this to be done with relative speed and ease to encourage rapid exploration and comparison. As the various loop types and orders are selected, parameters are automatically adjusted to keep the plots interesting — primarily to cause zero gain to occur at a frequency where phase is changing significantly — so, while the parameters can be modified, it may be best to do so on the simpler files first, leaving `ChsPlot` close to its original state. It might be instructive to compare Figs. 5.6 through 5.11 to similar plots generated using this program.

Since it is difficult to see the close-in (near $s = -1$) and far-out Nyquist pictures on the same plot, a zoom capability has been incorporated for the Nyquist plot in `ChsPlot`. It can be useful to compare the Nyquist plot to the Bode gain and phase plots to see what portion of the characteristic is being observed with a given magnification of the Nyquist plot. MATLAB now provides tools that make this feature of the script unnecessary but you may find one or the other preferable.

In particular, observe the relationship between the Bode, Evans, and Nyquist plots when the third-order conditionally stable loop similar to Fig. 5.11 is selected. We can see how the Evans plot crosses into the right-half plane at some gains and, using the Bode plot, can observe what these frequencies are, where the excess phase is below -180°. Using the Bode plot we can observe that the medium gain plot (obtained by choosing `zm`) has unity gain within the region of excess phase but the high and low gain plots (`zl` and `zh`) do not. We can observe how the Nyquist locus surrounds the -1 point for the `zm` plot, confirming instability, but not for the others. Here we will need the zoom capability to verify that the -1 point is or is not surrounded in the sense of a vector from -1 to the locus rotating a full circle as the locus is followed.

Note that output can be obtained by deleting the ";" at the end of an appropriate line. This can be very useful but may also produce a large amount of output. The following resources are available to help you understand the MATLAB programs associated with this book.

- the comments in the programs;
- the MATLAB Help utility;
- the MATLAB manual;
- the text of function programs (M-files).