The \texttt{bodeplot} package
version 1.1.1

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1 Introduction

Generate Bode, Nyquist, and Nichols plots for transfer functions in the canonical (TF) form

\[ G(s) = e^{-\frac{T_s b_m s^m + \cdots + b_1 s + b_0}{a_n s^n + \cdots + a_1 s + a_0}} \]  \hspace{1cm} (1)

and the zero-pole-gain (ZPK) form

\[ G(s) = K e^{\frac{-T_s (s - z_1)(s - z_2)\cdots(s - z_m)}{(s - p_1)(s - p_2)\cdots(s - p_n)}}. \]  \hspace{1cm} (2)

In the equations above, \( b_m, \ldots, b_0 \) and \( a_n, \ldots, a_0 \) are real coefficients, \( T \geq 0 \) is the loop delay, \( z_1, \ldots, z_m \) and \( p_1, \ldots, p_n \) are complex zeros and poles of the transfer function, respectively, and \( K \in \mathbb{R} \) is the loop gain.

For transfer functions in the ZPK format in (2) with zero delay, this package also supports linear and asymptotic approximation of Bode plots.

By default, all phase plots use degrees as units. Use the \texttt{rad} package option or the optional argument \texttt{tikz/\{phase unit=rad\}} to generate plots in radians. The \texttt{phase unit} key accepts either \texttt{rad} or \texttt{deg} as inputs and needs to be added to the \texttt{tikzpicture} environment that contains the plots.

By default, frequency inputs and outputs are in radians per second. Use the \texttt{Hz} package option or the optional argument \texttt{tikz/\{frequency unit=Hz\}} to generate plots in hertz. The \texttt{frequency unit} key accepts either \texttt{rad} or \texttt{Hz} as inputs and needs to be added to the \texttt{tikzpicture} environment that contains the plots.

1.1 External Dependencies

By default, the package uses \texttt{gnuplot} to do all the computations. If \texttt{gnuplot} is not available, the \texttt{pgf} package option can be used to do the calculations using the native \texttt{pgf} math engine. Compilation using the \texttt{pgf} math engine is typically slower, but the end result should be the identical (other than phase wrapping in the TF form, see limitations below).

1.2 Directory Structure

Since version 1.0.8, the \texttt{bodeplot} package places all \texttt{gnuplot} temporary files in the working directory. The package option \texttt{declutter} restores the original behavior where the temporary files are placed in a folder called \texttt{gnuplot}.

1.3 Limitations

- In \texttt{pgf} mode, Bode phase plots and Nichols charts in TF form wrap angles so that they are always between 0 and 360° or 0 and 2\pi radian. As such, these plots will show phase wrapping discontinuities. Since v1.1.1, in \texttt{gnuplot} mode, the package uses the \texttt{smooth unwrap} filter to correct wrapping discontinuities. As of now, I have not found a way to do this in \texttt{pgf} mode, any merge requests or ideas you may have are welcome!

- Use of the \texttt{declutter} option with other directory management tools such as a \texttt{tikzexternalize} prefix is not recommended.
2 TL;DR

All Bode plots in this section are for the transfer function (with and without a transport delay)

\[
G(s) = \frac{10(s + 0.1 + 0.5i)(s + 0.1 - 0.5i)}{(s + 0.5 + 10i)(s + 0.5 - 10i)} = \frac{s(10s^2 + 2s + 2.6)}{(s^2 + s + 100.25)}.
\]  

Bode plot in ZPK format

\[
\text{\BodeZPK{z/{0,{-0.1,-0.5},{-0.1,0.5}}, p/{{-0.5,-10},{-0.5,10}}, k/10}{0.01}{100}}
\]

Same Bode plot over the same frequency range but supplied in Hz, in TF format with arrow decoration, transport delay, unit, and color customization (the phase plot may show wrapping if the \texttt{pgf} package option is used)

\[
\text{\BodeTF[samples=1000, plot/mag/blue,thick, plot/ph/green,thick, tikz/\{\geq latex, phase unit=rad, frequency unit=Hz\}]{num/10,2,2.6,0, den/1,1,100.25}\{0.01/(2*pi)\{100/(2*pi)\}}
\]
Linear approximation with customization

Plot with delay and customization
Individual gain and phase plots with more customization

\begin{BodeMagPlot}\
\begin{scope}[\small]
\node at (0,3) {\textbf{Nichols chart}};
\end{scope}
\end{BodeMagPlot}

\begin{BodePhPlot}\
\begin{scope}[\small]
\node at (0,3) {Same Nichols chart in TF format (may show wrapping in \texttt{pgf} mode)};
\end{scope}
\end{BodePhPlot}
Multiple Nichols charts with customization

\begin{NicholsChart}
% ytick distance=20, 
% xtick distance=30 
(0.001) (100) 
\addNicholsZPKChart [red,samples=1000] ( \% 
% //1/(s-0.1,-0.5), (s+0.1,0.5)), 
% p://(-0.5,-10),(-0.5,10)), 
% k/10) 
\endNicholsChart

Nyquist plot

\NyquistZPK[plot/{red,thick,samples=1000}]
{\% 
% //1/(s-0.1,-0.5), (s+0.1,0.5)), 
% p://(-0.5,-10),(-0.5,10)), 
% k/10) 
\end{NicholsChart}

Nyquist plot in TF format with arrows

\NyquistTF[\% 
\% plot/{\% 
\% samples=1000, 
\% postaction=decorate, 
\% decoration={\% 
\% markings, 
\% mark= between positions 0.1 and 0.9 step 0.1 with \% \% \% arrow[stealth [length=2mm, blue]] \% \% \% } \% \% } \% \% } \% \% }

% 
% } \% 
\end{NicholsChart}
Multiple Nyquist plots with customization

\begin{NyquistPlot}[-30]{30}
\addNyquistZPKPlot[red,samples=1000]
\textstyle{/ (0,(-0.1,-0.5),(-0.1,0.5)),}
\textstyle{k/10}\%
\end{NyquistPlot}

\begin{NyquistPlot}
\addNyquistZPKPlot[blue,samples=1000]
\textstyle{/ (0,(-0.1,-0.5),(-0.1,0.5)),}
\textstyle{k/5}\%
\end{NyquistPlot}

Nyquist plots with additional commands, using two different macros

\begin{NyquistPlot}[-30]{30}
\addNyquistZPKPlot[blue,samples=1000]
\textstyle{/ (0,(-0.1,-0.5),(-0.1,0.5)),}
\textstyle{k/0.5}\%
\end{NyquistPlot}

\begin{NyquistPlot}
\addNyquistZPKPlot[blue,samples=1000]
\textstyle{/ (0,(-0.1,-0.5),(-0.1,0.5)),}
\textstyle{k/0.5}\%
\end{NyquistPlot}
3 Usage

In all the macros described here, the frequency limits supplied by the user are assumed to be in rad/s unless either the Hz package option is used or the optional argument `tikz/{frequency unit=Hz}` is supplied to the tikzpicture environment. All phase plots are generated in degrees unless either the rad package option is used or the optional argument `tikz/{frequency unit=rad}` is supplied to the tikzpicture environment.

3.1 Bode plots

\[ \text{BodeZPK} \]

\[
\begin{align*}
(z/\{\text{zeros}\}, p/\{\text{poles}\}, k/\{\text{gain}\}, d/\{\text{delay}\}) & \{\text{min-freq}\} & \{\text{max-freq}\}
\end{align*}
\]

Plots the Bode plot of a transfer function given in ZPK format using the groupplot environment. The three mandatory arguments include: (1) a list of tuples, comprised of the zeros, the poles, the gain, and the transport delay of the transfer function, (2) the lower end of the frequency range for the x-axis, and (3) the higher end of the frequency range for the x-axis. The zeros and the poles are complex numbers, entered as a comma-separated list of comma-separated lists, of the form \{real part 1, imaginary part 1\}, \{real part 2, imaginary part 2\}, ...}. If the imaginary part is not provided, it is assumed to be zero.

The optional argument is comprised of a comma separated list of tuples, either obj/typ/{opt}, or obj/{opt}, or just {opt}. Each tuple passes options to different pgfplots macros that generate the group, the axes, and the plots according to:

- Tuples of the form obj/typ/{opt}:
  - plot/typ/{opt}: modify plot properties by adding options \{opt\} to the \addplot macro for the magnitude plot if typ is mag and the phase plot if typ is ph.
  - axes/typ/{opt}: modify axis properties by adding options \{opt\} to the \nextgroupplot macro for the magnitude plot if typ is mag and the phase plot if typ is ph.
  - commands/typ/{opt}: add any valid TikZ commands (including the the parametric function generator macros in this package, such as \addBodeZPKPlots, \addBodeTFPlot, and \addBodeComponentPlot) to the magnitude plot if typ is mag and the phase plot if typ is ph. The commands passed to \opt need to be valid TikZ commands, separated by semicolons as usual. For example, a TikZ command is used in the description of the \BodeTF macro below to mark the gain crossover frequency on the Bode Magnitude plot.
  - approx/linear: plots linear approximation.
  - approx/asymptotic: plots asymptotic approximation.

- Tuples of the form obj/{opt}:
  - plot/{opt}: adds options \{opt\} to \addplot macros for both the magnitude and the phase plots.
  - axes/{opt}: adds options \{opt\} to \nextgroupplot macros for both the magnitude and the phase plots.
  - group/{opt}: adds options \{opt\} to the groupplot environment.
  - tikz/{opt}: adds options \{opt\} to the tikzpicture environment.
  - approx/linear: plots linear approximation.
  - approx/asymptotic: plots asymptotic approximation.

- Tuples of the form \{opt\} add all of the supplied options to \addplot macros for both the magnitude and the phase plots.
Figure 1: Output of the default $\texttt{BodeZPK}$ macro.

The options $\{\text{opt}\}$ can be any \texttt{key=value} options that are supported by the \texttt{pgfplots} macros they are added to.

For example, given a transfer function

$$G(s) = 10 \frac{s(s + 0.1 + 0.5i)(s + 0.1 - 0.5i)}{(s + 0.5 + 10i)(s + 0.5 - 10i)}, \quad (4)$$

its Bode plot over the frequency range $[0.01, 100]$ can be generated using

```latex
\texttt{BodeZPK}\{\text{blue, thick}\}
\{z/\{0,{-0.1,-0.5},{-0.1,0.5}\},p/\{-0.5,-10\},\{-0.5,10\}\},k/10\}
\{0.01\}{100}
```

which generates the plot in Figure 1. If a delay is not specified, it is assumed to be zero. If a gain is not specified, it is assumed to be 1. By default, each of the axes, excluding ticks and labels, are 5cm wide and 2.5cm high. The width and the height, along with other properties of the plots, the axes, and the group can be customized using native \texttt{pgf} keys as shown in the example below.

As demonstrated in this example, if a single comma-separated list of options is passed, it applies to both the magnitude and the phase plots. Without any optional arguments, we get a thick black Bode plot.

A linear approximation of the Bode plot with customization of the plots, the axes, and the group can be generated using

```latex
\texttt{BodeZPK}\{\text{plot/mag/\{red, thick\}, plot/ph/\{blue, thick\},}
\text{axes/mag/\{ytick distance=40, xmajor ticks=true,}
\text{xlabel=\{Frequency (rad/s)\}, axes/ph/\{ytick distance=90\},}
\text{group/\{group style=\{group size=2 by 1, horizontal sep=2cm,}
\text{width=4cm, height=2cm\}, approx/linear\}}
\{z/\{0,{-0.1,-0.5},{-0.1,0.5}\},p/\{-0.5,-10\},\{-0.5,10\}\},k/10\}
\{0.01\}{100}\}
```

which generates the plot in Figure 2.

\texttt{BodeTF} \texttt{BodeTF}\{(\text{obj1/typ1/\{\text{opt1}\}, obj2/typ2/\{\text{opt2}\},...)}\}
\{(\text{num/\{\text{coeffs}\}, den/\{\text{coeffs}\}, d/\{\text{delay}\}}\}
\{(\text{min-freq})\}{\text{\{max-freq\}}}

Plots the Bode plot of a transfer function given in TF format. The three mandatory arguments include: (1) a list of tuples comprised of the coefficients in the numerator and the denominator of the transfer function and the transport delay, (2) the lower end of the frequency range for the $x-$ axis, and (3) the higher end of the frequency range for the $x-$axis. The coefficients are entered as a comma-separated list, in order from the highest degree of $s$ to the lowest, with zeros for missing degrees. The optional arguments are the same as \texttt{BodeZPK}, except that linear/asymptotic approximation is not supported, so \texttt{approx/...} is ignored.
For example, given the same transfer function as (4) in TF form and with a small transport delay,
\[ G(s) = e^{-0.01s} \frac{s(10s^2 + 2s + 2.6)}{(s^2 + s + 100.25)}, \] (5)
its Bode plot over the frequency range [0.01, 100] can be generated using
\texttt{\textbackslash BodeTF[commands/mag/\{\texttt{\textbackslash node at (axis cs: 2.1,0)}\}
\{circle,fill,inner sep=0.05cm,label=below:{$\omega_{gc}$}\}]{};\}}\]
\{num/{10,2,2.6,0},den/{1,1,100.25},d/0.01\}
\{0.01\}{100}\}
which generates the plot in Figure 3. Note the 0 added to the numerator coefficients to account for the fact that the numerator does not have a constant term in it. Note the semicolon after the TikZ command passed to the \texttt{\textbackslash commands} option.

\texttt{\textbackslash BodeMagPlot (env.) \begin{BodeMagPlot}
\{\texttt{\textbackslash obj1/\{\texttt{\textbackslash opt1}\}}\},\texttt{\textbackslash obj2/\{\texttt{\textbackslash opt2}\}},\ldots\}\}
\{\texttt{\textbackslash addBode\ldots}\}
\end{BodeMagPlot}\}

The \texttt{\textbackslash BodeMagPlot} environment works in conjunction with the parametric function generator macros \texttt{\textbackslash addBodeZPKPlots}, \texttt{\textbackslash addBodeTFPlot}, and \texttt{\textbackslash addBodeComponentPlot}, intended to be used for magnitude plots. The optional argument is comprised of a comma separated list of tuples, either \texttt{\textbackslash obj/{\texttt{\textbackslash opt}}} or just \texttt{\textbackslash opt}. Each tuple passes options to different \texttt{pgfplots} macros that generate the axes and the plots according to:

- Tuples of the form \texttt{\textbackslash obj/{\texttt{\textbackslash opt}}}:  
  - \texttt{\textbackslash tikz/{\texttt{\textbackslash opt}}}: modify picture properties by adding options \texttt{\textbackslash opt} to the \texttt{tikzpicture} environment.
axes/{opt}: modify axis properties by adding options {opt} to the semilogaxis environment.

commands/{opt}: add any valid TikZ commands inside semilogaxis environment. The commands passed to opt need to be valid TikZ commands, separated by semicolons as usual.

- Tuples of the form {opt} are passed directly to the semilogaxis environment. The frequency limits are translated to the x-axis limits and the domain of the semilogaxis environment. Example usage in the description of \addBodeZPKPlots, \addBodeTFPlot, and \addBodeComponentPlot.

\begin{BodePhPlot}(env.)
\begin{BodePhPlot}{⟨obj1/{⟨opt1⟩},obj2/{⟨opt2⟩},...⟩}
\addBode...
\end{BodePhPlot}
\end{BodePhPlot}
\addBodeZPKPlots {⟨approx1/{⟨opt1⟩},approx2/{⟨opt2⟩},...⟩}
{⟨plot-type⟩}
{⟨z/{zeros}⟩,p/{⟨poles⟩},k/{⟨gain⟩},d/{⟨delay⟩}⟩}
Generates the appropriate parametric functions and supplies them to multiple \addplot macros, one for each approx/{opt} pair in the optional argument. If no optional argument is supplied, then a single \addplot command corresponding to a thick true Bode plot is generated. If an optional argument is supplied, it needs to be one of true/{opt}, linear/{opt}, or asymptotic/{opt}. This macro can be used inside any semilogaxis environment as long as a domain for the x-axis is supplied through either the approx/{opt} interface or directly in the optional argument of the semilogaxis environment. Use with the BodePlot environment supplied with this package is recommended. The second mandatory argument, plot-type is either magnitude or phase. If it is not equal to phase, it is assumed to be magnitude. The last mandatory argument is the same as \BodeZPK.

For example, given the transfer function in (4), its linear, asymptotic, and true Bode plots can be superimposed using

\begin{BodePhPlot}
\addBodeTFPlot{⟨plot-options⟩}
{⟨plot-type⟩}
{⟨num/{coeffs}⟩,den/{coeffs},d/{⟨delay⟩}}
Generates a single parametric function for either Bode magnitude or phase plot of a transfer function in TF form. The generated parametric function is passed to the \addplot macro. This macro can be used inside any semilogaxis environment as long as a domain for the x-axis is supplied through either the plot-options interface or directly in the optional argument of the container semilogaxis environment. Use
Figure 4: Superimposed approximate and true Bode plots using the \texttt{BodeMagPlot} and \texttt{BodePhPlot} environments and the \texttt{addBodeZPKPlots} macro.

with the \texttt{BodePlot} environment supplied with this package is recommended. The second mandatory argument, \texttt{plot-type} is either magnitude or phase. If it is not equal to phase, it is assumed to be magnitude. The last mandatory argument is the same as \texttt{BodeTF}.

\begin{addBodeComponentPlot}[(plot-options)]{(plot-command)}\end{addBodeComponentPlot}

Generates a single parametric function corresponding to the mandatory argument \texttt{plot-command} and passes it to the \texttt{addplot} macro. The plot command can be any parametric function that uses \texttt{t} as the independent variable. The parametric function must be \texttt{gnuplot} compatible (or \texttt{pgfplots} compatible if the package is loaded using the \texttt{pgf} option). The intended use of this macro is to plot the parametric functions generated using the basic component macros described in Section 3.1.1 below.

\subsection{Basic components up to first order}

\texttt{\TypeFeatureApprox{Type}{Feature}{Approx}}

This entry describes 20 different macros of the form \texttt{\TypeFeatureApprox} that take the real part and the imaginary part of a complex number as arguments. The \texttt{Type} in the macro name should be replaced by either \texttt{Mag} or \texttt{Ph} to generate a parametric function corresponding to the magnitude or the phase plot, respectively. The \texttt{Feature} in the macro name should be replaced by one of \texttt{K}, \texttt{Pole}, \texttt{Zero}, or \texttt{Del}, to generate the Bode plot of a gain, a complex pole, a complex zero, or a transport delay, respectively. If the \texttt{Feature} is set to either \texttt{K} or \texttt{Del}, the \texttt{imaginary-part} mandatory argument is ignored. The \texttt{Approx} in the macro name should either be removed, or it should be replaced by \texttt{Lin} or \texttt{Asymp} to generate the true Bode plot, the linear approximation, or the asymptotic approximation, respectively. If the \texttt{Feature} is set to \texttt{Del}, then \texttt{Approx} has to be removed. For example,

- \texttt{\MagK{k}{0}} or \texttt{\MagK{k}{400}} generates a parametric function for the true Bode magnitude of $G(s) = k$
- \texttt{\PhPoleLin{a}{b}} generates a parametric function for the linear approximation of the Bode phase of $G(s) = 1/(s-a-b)$.
- \texttt{\PhDel{T}{200}} or \texttt{\PhDel{T}{0}} generates a parametric function for the Bode phase of $G(s) = e^{-Ts}$.

All 20 of the macros defined by combinations of \texttt{Type}, \texttt{Feature}, and \texttt{Approx}, and any \texttt{gnuplot} (or \texttt{pgfplots} if the \texttt{pgf} class option is loaded) compatible function of the 20 macros can be used as \texttt{plot-command} in the \texttt{addBodeComponentPlot} macro. This is sufficient to generate the Bode plot of any rational transfer function. For example, the Bode phase plot in Figure 4 can also be generated using:

\begin{BodePhPlot}{ytick distance=90}{0.01}{100}\addBodeComponentPlot[black,thick]{\PhZero{0}{0} + \PhZero{-0.1}{-0.5} + \PhZero{-0.1}{0.5} + \PhPole{-0.5}{10} + \PhPole{-0.5}{-10} + \PhK{10}{0}}\addBodeComponentPlot[red,dashed,thick]{\PhZeroLin{0}{0} +}

\end{BodePhPlot}
Figure 5: Superimposed approximate and true Bode Phase plot using the \texttt{BodePhasePlot} environment, the \texttt{addBodeComponentPlot} macro, and several macros of the \texttt{TypeFeatureApprox} form.

Figure 6: Resonant peak in asymptotic Bode plot using \texttt{MagSOFeaturePeak}.

\begin{verbatim}
\addBodeComponentPlot[blue,dotted,thick] {
\PhZeroAsymp{0}{0} + \PhZeroLin{-0.1}{-0.5} + \PhZeroLin{-0.1}{0.5} + \PhZeroLin{-0.1}{10} + \PhPoleLin{-0.5}{-10} + \PhPoleLin{-0.5}{10} + \PhKLin{10}{20}}
\addBodeComponentPlot[red,dashed,thick] {
\MagSOPoles{0.2}{1}}
\addBodeComponentPlot[black,thick] {
\MagSOPolesLin{0.2}{1}}
\end{BodePhPlot}
\end{verbatim}

which gives us the plot in Figure 5.

3.1.2 Basic components of the second order

\begin{verbatim}
\MagSOFeaturePeak[\{draw-options\}]{\{a1\}}{\{a0\}}
\end{verbatim}

This entry describes 2 different macros of the form \texttt{MagSOFeaturePeak} that take the the coefficients $a_1$ and $a_0$ of a general second order system as inputs, and draw a resonant peak using the \texttt{draw TikZ} macro. The \texttt{Feature} in the macro name should be replaced by either \texttt{Poles} or \texttt{Zeros} to generate a peak for poles and a valley for zeros, respectively. For example, the command

\begin{verbatim}
\begin{BodeMagPlot}[xlabel={}]\{0.1\}\{10\}
\addBodeComponentPlot[red,dashed,thick] {\MagSOPoles{0.2}{1}}
\addBodeComponentPlot[black,thick] {\MagSOPolesLin{0.2}{1}}
\MagSOPolesPeak[thick]{0.2}{1}
\end{BodeMagPlot}
\end{verbatim}

generates the plot in Figure 6.
This entry describes 12 different macros of the form \TypeCSFeatureApprox that take the damping ratio, \( \zeta \), and the natural frequency, \( \omega_n \), of a canonical second order system as inputs. The Type in the macro name should be replaced by either Mag or Ph to generate a parametric function corresponding to the magnitude or the phase plot, respectively. The Feature in the macro name should be replaced by either Poles or Zeros to generate the Bode plot of \( G(s) = \frac{1}{s + 2\zeta\omega_n s + \omega_n^2} \) or \( G(s) = s^2 + 2\zeta\omega_n s + \omega_n^2 \), respectively. The Approx in the macro name should either be removed, or it should be replaced by Lin or Asym to generate the true Bode plot, the linear approximation, or the asymptotic approximation, respectively.

\MagCSFeaturePeak \MagCSFeaturePeak\{\text{draw-options}\}\{\text{zeta}\}\{\text{omega-n}\}
This entry describes 2 different macros of the form \MagCSFeaturePeak that take the damping ratio, \( \zeta \), and the natural frequency, \( \omega_n \), of a canonical second order system as inputs, and draw a resonant peak using the \draw TikZ macro. The Feature in the macro name should be replaced by either Poles or Zeros to generate a peak for poles and a valley for zeros, respectively.

\MagCCFeaturePeak \MagCCFeaturePeak\{\text{draw-options}\}\{\text{real-part}\}\{\text{imaginary-part}\}
This entry describes 2 different macros of the form \MagCCFeaturePeak that take the real and imaginary parts of a pair of complex conjugate poles or zeros as inputs, and draw a resonant peak using the \draw TikZ macro. The Feature in the macro name should be replaced by either Poles or Zeros to generate a peak for poles and a valley for zeros, respectively.

### 3.2 Nyquist plots

\NyquistZPK \NyquistZPK\{\text{plot/\{opt\}},\text{axes/\{opt\}}\}
\{\text{z/\{zeros\}},\text{p/\{poles\}},\text{k/\{gain\}},\text{d/\{delay\}}\}
\{\text{min-freq}\}\{\text{max-freq}\}
Plots the Nyquist plot of a transfer function given in ZPK format with a thick red + marking the critical point (-1,0). The mandatory arguments are the same as \BodeZPK. Since there is only one plot in a Nyquist diagram, the \text{typ} specifier in the optional argument tuples is not needed. As such, the supported optional argument tuples are \text{plot/\{opt\}}, which passes \{opt\} to \text{addplot}, \text{axes/\{opt\}}, which passes \{opt\} to the \text{axis} environment, and \text{tikz/\{opt\}}, which passes \{\text{opt}\} to the \text{tikzpicture} environment. Asymptotic/linear approximations are not supported in Nyquist plots. If just \{\text{opt}\} is provided as the optional argument, it is interpreted as \text{plot/\{opt\}}. Arrows to indicate the direction of increasing \( \omega \) can be added by adding \text{usetikzlibrary\{decorations.markings\}} and \text{usetikzlibrary\{arrows.meta\}} to the preamble and then passing a tuple of the form

\text{plot/\{postaction=decorate,\text{\{decorations\},\text{\{markings\},\text{\text{mark=\{between\ positions\ 0.1\ and\ 0.9\ step\ 5em\ with\\{\text{\text{arrow\{\text{Stealth\[\text{length=2mm,\ blue\}\}\}}}\}}\}}}\}}} \text{Dimension too big.}

For example, the command
\NyquistZPK\{\text{plot/\{\text{red,thick,samples=2000\}},\text{axes/\{\text{blue,thick\}}}\}
\{\text{z/\{0,{-0.1,-0.5},{-0.1,0.5}\}},\text{p/\{-0.5,-10\},\{-0.5,10\}},\text{k/10\}}
\{-30\}\{30\}
generates the Nyquist plot in Figure 7.

\NyquistTF \NyquistTF\{\text{\{plot/\{\text{green,thick,samples=500\}},\text{\{postaction=decorate,\text{\{decorations\},\text{\{markings\},\text{\text{mark=\{between\ positions\ 0.1\ and\ 0.9\ step\ 5em\ with\\{\text{\text{arrow\{\text{Stealth\[\text{length=2mm,\ blue\}\}}}\}}}\}}}\}}}\}}\}}
Figure 7: Output of the \texttt{NyquistZPK} macro.

Figure 8: Output of the \texttt{NyquistTF} macro with direction arrows. Increasing the number of samples can cause \texttt{decorations.markings} to throw errors.

\begin{NyquistPlot}
\begin{macrocode}
\addNyquist...
\end{NyquistPlot}
\end{macrocode}

The \texttt{NyquistPlot} environment works in conjunction with the parametric function generator macros \texttt{addNyquistZPKPlot} and \texttt{addNyquistTFPlot}. The optional argument is comprised of a comma separated list of tuples, either \texttt{obj/{opt}} or just \texttt{{opt}}. Each tuple passes options to different \texttt{pgfplots} macros that generate the axes and the plots according to:

- Tuples of the form \texttt{obj/{opt}}:
  - \texttt{tikz/{opt}}: modify picture properties by adding options \texttt{opt} to the \texttt{tikzpicture} environment.
  - \texttt{axes/{opt}}: modify axis properties by adding options \texttt{opt} to the \texttt{axis} environment.
  - \texttt{commands/{opt}}: add any valid TikZ commands inside \texttt{axis} environment. The commands passed to \texttt{opt} need to be valid TikZ commands, separated
by semicolons as usual.

- Tuples of the form \{opt\} are passed directly to the axis environment.

The frequency limits are translated to the x-axis limits and the domain of the axis environment.

\addNyquistZPKPlot \addNyquistZPKPlot[⟨plot-options⟩]
{(z/{zeros},p/{poles},k/{gain},d/{delay})}
Generates a twp parametric functions for the magnitude and the phase a transfer function in ZPK form. The generated magnitude and phase parametric functions are converted to real and imaginary part parametric functions and passed to the addplot macro. This macro can be used inside any axis environment as long as a domain for the x-axis is supplied through either the plot-options interface or directly in the optional argument of the container axis environment. Use with the NyquistPlot environment supplied with this package is recommended. The mandatory argument is the same as \BodeZPK.

\addNyquistTFPlot \addNyquistTFPlot[⟨plot-options⟩]
{(num/{coeffs},den/{coeffs},d/{delay})}
Similar to \addNyquistZPKPlot, with a transfer function input in the TF form.

### 3.3 Nichols charts

\NicholsZPK \NicholsZPK[⟨plot/{(opt)},axes/{(opt)}⟩]
{(z/{zeros},p/{poles},k/{gain},d/{delay})}
{(min-freq)⟨max-freq⟩}
Nichols chart of a transfer function given in ZPK format. Same arguments as \NyquistZPK.

\NicholsTF \NicholsTF[⟨plot/{(opt)},axes/{(opt)}⟩]
{(num/{coeffs},den/{coeffs},d/{delay})}
{(min-freq)⟨max-freq⟩}
Nichols chart of a transfer function given in TF format. Same arguments as \NyquistTF. For example, the command
\NicholsTF[plot/{green,thick,samples=2000}]
{num/{10,2,2.6,0},den/{1,1,100.25},d/0.01}
{0.001}{100}
generates the Nichols chart in Figure 9.

\NicholsChart \begin{NicholsChart}{⟨obj1/{(opt1)},obj2/{(opt2)},...⟩}
{⟨min-frequency⟩}{⟨max-frequency⟩}
\addNichols...
\end{NicholsChart}
The **NicholsChart** environment works in conjunction with the parametric function generator macros `\addNicholsZPKChart` and `\addNicholsTFChart`. The optional argument is comprised of a comma separated list of tuples, either `obj/{opt}` or just `{opt}`. Each tuple passes options to different `pgfplots` macros that generate the axes and the plots according to:

- **Tuples of the form** `obj/{opt}`:
  - `tikz/{opt}`: modify picture properties by adding options `{opt}` to the `tikzpicture` environment.
  - `axes/{opt}`: modify axis properties by adding options `{opt}` to the `axis` environment.
  - `commands/{opt}`: add any valid TikZ commands inside `axis` environment. The commands passed to `{opt}` need to be valid TikZ commands, separated by semicolons as usual.

- **Tuples of the form** `{opt}` are passed directly to the `axis` environment.

The frequency limits are translated to the x-axis limits and the domain of the `axis` environment.

### \addNicholsZPKChart

\addNicholsZPKChart[(plot-options)]
{(z/{zeros},p/{poles},k/{gain},d/{delay})}

Generates two parametric functions for the magnitude and the phase a transfer function in ZPK form. The generated magnitude and phase parametric functions are passed to the `\addplot` macro. This macro can be used inside any `axis` environment as long as a domain for the x-axis is supplied through either the `plot-options` interface or directly in the optional argument of the container `axis` environment. Use with the `NicholsChart` environment supplied with this package is recommended. The mandatory argument is the same as `\BodeZPK`.

### \addNicholsTFChart

\addNicholsTFChart[(plot-options)]
{(num/{coeffs},den/{coeffs},d/{delay})}

Similar to `\addNicholsZPKChart`, with a transfer function input in the TF form.
4 Implementation

4.1 Initialization

This code is needed to support both \texttt{pgfplots} and \texttt{gnuplot} simultaneously. New macros are defined for the \texttt{pow} and \texttt{mod} functions to address differences between the two math engines. We start by processing the class options.

\begin{verbatim}
\newif\if@pgfarg\@pgfargfalse
\DeclareOption{pgf}{\@pgfargtrue}
\newif\if@declutterarg\@declutterargfalse
\DeclareOption{declutter}{\@declutterargtrue}
\newif\if@radarg\@radargfalse
\DeclareOption{rad}{\@radargtrue}
\newif\if@hzarg\@hzargfalse
\DeclareOption{Hz}{\@hzargtrue}
\ProcessOptions\relax
\end{verbatim}

Then, we define two new macros to unify \texttt{pgfplots} and \texttt{gnuplot}.

\begin{verbatim}
\newcommand{\n@mod}[2]{(#1)-(floor((#1)/(#2))*(#2))}
\if@pgfarg
\newcommand{\n@pow}[2]{(#1)**(#2)}
\pgfplotsset{
trig format plots=rad
}
\else
\newcommand{\n@pow}[2]{(#1)^(#2)}
\fi
\end{verbatim}

Then, we create a counter so that a new data table is generated and for each new plot. If the plot macros have not changed, the tables, once generated, can be reused by \texttt{gnuplot}, which reduces compilation time. The \texttt{declutter} option is used to enable the \texttt{gnuplot} directory to declutter the working directory.

\begin{verbatim}
\newcounter{gnuplot@id}
\setcounter{gnuplot@id}{0}
\if@declutterarg
\edef\bodeplot@prefix{gnuplot/\jobname}
\else
\edef\bodeplot@prefix{\jobname}
\fi
\tikzset{
\gnuplot@prefix/.style={
id=\arabic{gnuplot@id},
\prefix=\bodeplot@prefix
}}
\end{verbatim}

If the operating system is not Windows, and if the \texttt{declutter} option is not passed, we create the \texttt{gnuplot} folder if it does not already exist.

\begin{verbatim}
\ifwindows\else
\if@declutterarg
\immediate\write18{mkdir -p gnuplot}
\fi
\fi
\end{verbatim}

\texttt{bode@style} Default axis properties for all plot macros are collected in this \texttt{pgf} style.

\begin{verbatim}
\pgfplotsset{
\end{verbatim}
bodestyle/.style = {
    label style={font=\footnotesize},
    tick label style={font=\footnotesize},
    grid=both,
    major grid style={color=gray!80},
    minor grid style={color=gray!20},
    x label style={at={(ticklabel cs:0.5)},anchor=near ticklabel},
    y label style={at={(ticklabel cs:0.5)},anchor=near ticklabel},
    scale only axis,
    samples=200,
    width=5cm,
    log basis x=10
}

These macros handle the Hz and rad class options and two new pgf keys named frequency unit and phase unit for conversion of frequency and phase units, respectively.

\begin{align*}
\pgfplotsset{freq@filter/.style = {}}
\def\freq@scale{1}
\pgfplotsset{freq@label/.style = {xlabel = {Frequency (rad/s)}}}
\pgfplotsset{ph@x@label/.style = {xlabel={Phase (deg)}}}
\pgfplotsset{ph@y@label/.style = {ylabel={Phase (deg)}}}
\def\ph@scale{180/pi}
\if@radarg
\pgfplotsset{ph@y@label/.style = {ylabel={Phase (rad)}}}
\pgfplotsset{ph@x@label/.style = {xlabel={Phase (rad)}}}
\def\ph@scale{1}
\fi
\if@hzarg
\def\freq@scale{2*pi}
\pgfplotsset{freq@label/.style = {xlabel = {Frequency (Hz)}}}
\if@pgfarg
\pgfplotsset{freq@filter/.style = {x filter/.expression={x-log10(2*pi)}}}
\fi
\fi
\end{align*}
\tikzset{
    phase unit/.initial={deg},
    phase unit/.default={deg},
    phase unit/.is choice,
    phase unit/deg/.code={
        \renewcommand{\ph@scale}{180/pi}
        \pgfplotsset{ph@x@label/.style = {xlabel={Phase (deg)}}}
        \pgfplotsset{ph@y@label/.style = {ylabel={Phase (deg)}}}
    },
    phase unit/rad/.code={
        \renewcommand{\ph@scale}{1}
        \pgfplotsset{ph@y@label/.style = {ylabel={Phase (rad)}}}
        \pgfplotsset{ph@x@label/.style = {xlabel={Phase (rad)}}}
    },
    frequency unit/.initial={rad},
    frequency unit/.default={rad},
    frequency unit/.is choice,
    frequency unit/Hz/.code={
        \renewcommand{\freq@scale}{2*pi}
        \pgfplotsset{freq@label/.style = {xlabel = {Frequency (Hz)}}}
        \if@pgfarg
        \pgfplotsset{freq@filter/.style = {x filter/.expression={x-log10(2*pi)}}}
        \fi
    },
    frequency unit/rad/.code={
}
4.2 Parametric function generators for poles, zeros, gains, and delays.

All calculations are carried out assuming that frequency inputs are in \( \text{rad/s} \). Magnitude outputs are in \( \text{dB} \) and phase outputs are in degrees or radians, depending on the value of \( \phi@scale \).

\( \text{MagK} \) True, linear, and asymptotic magnitude and phase parametric functions for a pure gain \( G(s) = k + 0i \). The macros take two arguments corresponding to real and imaginary part of the gain to facilitate code reuse between delays, gains, poles, and zeros, but only real gains are supported. The second argument, if supplied, is ignored.

\( \text{MagKAsymp} \)
\( \text{MagKLin} \)

\( \text{PhKAsymp} \)
\( \text{PhKLin} \)

\( \text{MagDel} \) True magnitude and phase parametric functions for a pure delay \( G(s) = e^{-Ts} \). The macros take two arguments corresponding to real and imaginary part of the gain to facilitate code reuse between delays, gains, poles, and zeros, but only real gains are supported. The second argument, if supplied, is ignored.

\( \text{MagPole} \) These macros are the building blocks for most of the plotting functions provided by this package. We start with Parametric function for the true magnitude of a complex pole.

\( \text{MagPoleAsymp} \)
\( \text{MagPoleLin} \)

\( \text{PhPoleAsymp} \)
\( \text{PhPoleLin} \)

Parametric function for linear approximation of the magnitude of a complex pole.

Parametric function for asymptotic approximation of the magnitude of a complex pole, same as linear approximation.

Parametric function for the true phase of a complex pole.

Parametric function for linear approximation of the phase of a complex pole.

Parametric function for asymptotic approximation of the phase of a complex pole.
135 \(2 > 0? (\#1 > 0? 3\pi/2: -\pi/2) : -\pi/2\) :
136 (-atan2(-#2, -(#1)) + (log10(t / (sqrt(@pow(#1}{2} + @pow(#2}{2}))))/(2*log10(\sqrt(4*\@pow(#1}{2}))/(@pow(#1}{2} + \@pow(#2}{2})))))*((#2 > 0? (\#1 > 0? 3\pi/2: -\pi/2) : -\pi/2) + atan2(-#2, -(#1)))/
139 (log10(\@pow(#1}{2} + @pow(#2}{2})))))*\phase{scale}

Parametric function for asymptotic approximation of the phase of a complex pole.

\newcommand*{\PhPoleAsymp}{\{t < (sqrt(\@pow(#1}{2} + @pow(#2}{2})) ? -atan2(-#2, -(#1)) : (#2 > 0? (\#1 > 0? 3\pi/2: -\pi/2) : -\pi/2)\} * \phase{scale}}

Plots of zeros are defined to be negative of plots of poles. The \(\theta\) is necessary due to a bug in gnuplot (fixed in version 5.4, patchlevel 3).

\newcommand*{\MagZero}{0-\MagPole}
\newcommand*{\MagZeroLin}{0-\MagPoleLin}
\newcommand*{\MagZeroAsymp}{0-\MagPoleAsymp}
\newcommand*{\PhZero}{0-\PhPole}
\newcommand*{\PhZeroLin}{0-\PhPoleLin}
\newcommand*{\PhZeroAsymp}{0-\PhPoleAsymp}

4.3 Second order systems.

Although second order systems can be dealt with using the macros defined so far, the following dedicated macros for second order systems involve less computation.

Consider the canonical second order transfer function \(G(s) = \frac{1}{s^2 + 2\zeta\omega_n s + \omega_n^2}\). We start with true, linear, and asymptotic magnitude plots for this transfer function.

\newcommand*{\MagCSPoles}{\{-20*log10(sqrt(@pow(#1}{2} - @pow(#2}{2}))\}}
\newcommand*{\MagCSPolesLin}{\{(t < #2 ? -40*log10(#2) : -40*log10(t))\}}
\newcommand*{\MagCSPolesAsymp}{\MagCSPolesLin}

Then, we have true, linear, and asymptotic phase plots for the canonical second order transfer function.

\newcommand*{\PhCSPoles}{\{-atan2((2*(#1)*(#2)*t),(@pow(#2}{2} - @pow(#1}{2}))\} * \phase{scale}}
\newcommand*{\PhCSPolesLin}{\{(t < (#2 / (\@pow(10}{abs(#1)})) ? 0 : (t >= (#2 * (\@pow(10}{abs(#1)})) ? (#1 > 0 ? -pi : pi) : (#1 > 0 ? (-pi*(log10(t*(\@pow(10}{abs(#1)})))/(2*#1)) : (pi*(log10(t*(\@pow(10}{abs(#1)})))/(2*abs(#1))))\} * \phase{scale}}
\newcommand*{\PhCSPolesAsymp}{\{(#1 > 0 ? (t < #2 ? 0 : -pi) : (t < #2 ? 0 : pi))\} * \phase{scale}}

Plots of the inverse function \(G(s) = s^2 + 2\zeta\omega_n s + \omega_n^2\) are defined to be negative of plots of poles. The \(\theta\) is necessary due to a bug in gnuplot (fixed in version 5.4, patchlevel 3).

\newcommand*{\MagCSZeros}{0-\MagCSPoles}
\newcommand*{\MagCSZerosLin}{0-\MagCSPolesLin}
\newcommand*{\MagCSZerosAsymp}{0-\MagCSPolesAsymp}
\newcommand*{\PhCSZeros}{0-\PhCSPoles}
\newcommand*{\PhCSZerosLin}{0-\PhCSPolesLin}
\newcommand*{\PhCSZerosAsymp}{0-\PhCSPolesAsymp}

\newcommand*{\MagCSPolesPeak}{\MagCSPolesPeak}
\newcommand*{\MagCSZerosPeak}{\MagCSZerosPeak}

These macros are used to add a resonant peak to linear and asymptotic plots of canonical second order poles and zeros. Since the plots are parametric, a separate \draw command is needed to add a vertical arrow.

\newcommand*{\MagCSPolesPeak}[3]{\draw[#3,->] (axis cs:{#2},-#1) -- (axis cs:{#3},-#1)}}
Consider a general second order transfer function \( G(s) = \frac{1}{s^2 + as + b} \). We start with true, linear, and asymptotic magnitude plots for this transfer function.

Then, we have true, linear, and asymptotic phase plots for the general second order transfer function.

The plots of the inverse function \( G(s) = s^2 + as + b \) are defined to be negative of plots of poles. The 0- is necessary due to a bug in gnuplot (fixed in version 5.4, patchlevel 3).

These macros are used to add a resonant peak to linear and asymptotic plots of general second order poles and zeros. Since the plots are parametric, a separate \texttt{\textbackslash draw} command is needed to add a vertical arrow.

\section*{4.4 Commands for Bode plots}

\subsection*{4.4.1 User macros}

\texttt{\textbackslash BodeZPK}

This macro takes lists of complex poles and zeros of the form \{re,im\}, and values of gain and delay as inputs and constructs parametric functions for the Bode magnitude and phase plots. This is done by adding together the parametric functions generated by the macros for individual zeros, poles, gain, and delay, described above. The parametric functions are then plotted in a \texttt{tikzpicture} environment using the \texttt{\addplot} macro. Unless the package is loaded with the option \texttt{pgf}, the parametric functions are evaluated using \texttt{gnuplot}.
Most of the work is done by the \texttt{\textbackslash parse@opt} and the \texttt{\textbackslash build@ZPK@plot} macros, described in the 'Internal macros' section. The former is used to parse the optional arguments and the latter to extract poles, zeros, gain, and delay from the first mandatory argument and to generate macros \texttt{\textbackslash func@mag} and \texttt{\textbackslash func@ph} that hold the magnitude and phase parametric functions. The \texttt{\textbackslash noexpand} macros below are needed to so that only the macro \texttt{\textbackslash opt@group} is expanded.

```
\begin{verbatim}
\parse@opt{#1}
\gdef\func@mag{}
\gdef\func@ph{}
edef\temp@cmd{\noexpand\begin{tikzpicture} \unexpanded{\opt@tikz}}
\temp@cmd
\build@ZPK@plot{\func@mag}{\func@ph}{\opt@approx}{#2}
edef\temp@cmd{\noexpand\begin{groupplot}[
    bode@style,
    xmin=#3,
    xmax=#4,
    domain=#3*\freq@scale:#4*\freq@scale,
    height=2.5cm,
    xmode=log,
    group style = {group size = 1 by 2, vertical sep=0.25cm},
    \opt@group
    ]}
\temp@cmd
\end{verbatim}
```

To ensure frequency tick marks on magnitude and the phase plots are always aligned, we use the \texttt{\textbackslash groupplot} library. The \texttt{\textbackslash noexpand} and \texttt{\textbackslash unexpanded\textbackslash expandafter} macros below are used to expand macros in the plot and group optional arguments.

```
\begin{verbatim}
edef\temp@mag@cmd{\noexpand\nextgroupplot [ylabel={Gain (dB)}, xmajor ticks=false, \optmag@axes]
edef\temp@ph@cmd{\noexpand\nextgroupplot [\optph@axes]\addplot [freq@filter, variable=t, thick, \optph@plot]}
\if@pgfarg\temp@mag@cmd {\func@mag}; \optmag@commands \temp@ph@cmd {\func@ph}; \optph@commands \else
\stepcounter{gnuplot@id}
\temp@mag@cmd gnuplot [raw gnuplot, gnuplot@prefix]
\optmag@commands
\temp@ph@cmd gnuplot [raw gnuplot, gnuplot@prefix]
\optph@commands
\end{verbatim}
```

In \texttt{\textbackslash gnuplot} mode, we increment the \texttt{\textbackslash gnuplot@id} counter before every plot to make sure that new and reusable \texttt{\textbackslash gnuplot} and \texttt{\textbackslash table} files are generated for every plot. We use \texttt{\textbackslash raw gnuplot} to make sure that the tables generated by \texttt{\textbackslash gnuplot} use the correct phase and frequency units as supplied by the user.

```
\begin{verbatim}
\stepcounter{gnuplot@id}
\temp@mag@cmd gnuplot [raw gnuplot, gnuplot@prefix]
{ set table \$meta;
  set dummy t;
  set logscale x 10;
  set xrange [\#3*\freq@scale:#4*\freq@scale];
  set samples \pgfkeys{\pgfplots\samples};
  plot \func@mag;
  set table \"bodeplot\prefix\arabic{\gnuplot@id}.table\";
  plot "$\$meta" using ($1/(\freq@scale))::($2);
}
\optmag@commands
\temp@ph@cmd gnuplot [raw gnuplot, gnuplot@prefix]
{ set table \$meta;
  set dummy t;
  set logscale x 10;
  set xrange [\#3*\freq@scale:#4*\freq@scale];
  set samples \pgfkeys{\pgfplots\samples};
\end{verbatim}
```
\BodeTF Implementation of this macro is very similar to the \BodeZPK macro above. The only difference is the lack of linear and asymptotic plots and slightly different parsing of the mandatory arguments.

\newcommand{\BodeTF}[4][]{
\parse@opt{#1}
\gdef\func@mag{}
\gdef\func@ph{}
\edef\temp@cmd{\noexpand\begin{tikzpicture} \[unexpanded\expandafter{\opt@tikz}]}
\temp@cmd
\build@TF@plot{\func@mag}{\func@ph}{#2}
\edef\temp@cmd{\noexpand\begin{groupplot}\[bode@style,\nxmin=#3,\nxmax=#4,\ndomain=#3*\freq@scale:#4*\freq@scale,\nheight=2.5cm,\nxmode=log,\ngroup style = {group size = 1 by 2,vertical sep=0.25cm},\n\opt@group\n\]}\temp@cmd
\edef\temp@mag@cmd{\noexpand\nextgroupplot \[ylabel={Gain (dB)}, \xmajorticks=false, \optmag@axes\]}
\edef\temp@ph@cmd{\noexpand\nextgroupplot \[\func@ph\]{\n@mod{\func@ph}{2*pi*\ph@scale}}\n\optph@commands\n}\if@pgfarg\temp@mag@cmd {\func@mag};\optmag@commands\temp@ph@cmd {\n@mod{\func@ph}{2*pi*\ph@scale}};\optph@commands\else\stepcounter{gnuplot@id}\temp@mag@cmd gnuplot \[raw gnuplot, gnuplot@prefix\]\temp@ph@cmd gnuplot \[raw gnuplot, gnuplot@prefix\]\end{tikzpicture}\end{groupplot}\end{tikzpicture}\else\stepcounter{gnuplot@id}\temp@mag@cmd gnuplot \[raw gnuplot, gnuplot@prefix\]\temp@ph@cmd gnuplot \[raw gnuplot, gnuplot@prefix\]\end{tikzpicture}\end{groupplot}\end{tikzpicture}\fi\end{groupplot}\end{tikzpicture}

\BodeTF
\addBodeZPKPlots  This macro is designed to issues multiple \addplot macros for the same set of poles, zeros, gain, and delay. All of the work is done by the \build@ZPK@plot macro.
\newcommand{\addBodeZPKPlots}[3][true/{}]{
\foreach \approx/\opt in (#1) {
  \gdef\plot@macro{}
  \gdef\temp@macro{}
  \ifnum\pdf@strcmp{#2}{phase}=0
    \build@ZPK@plot{\temp@macro}{\plot@macro}{\approx}{#3}
  \else
    \build@ZPK@plot{\plot@macro}{\temp@macro}{\approx}{#3}
  \fi
  \edef\supplied@domain{\pgfkeysvalueof{/pgfplots/domain}}
  \edef\domain@start{\expandafter\get@interval@start\supplied@domain\@nil}
  \edef\domain@end{\expandafter\get@interval@end\supplied@domain\@nil}
  \if@pgfarg
    \edef\temp@cmd{\noexpand\addplot [freq@filter, domain=\domain@start:\domain@end, variable=t, thick, \opt]
      \plot@macro;}
  \else
    \stepcounter{gnuplot@id}
    \edef\temp@cmd{\noexpand\addplot [variable=t, thick, \opt]
      gnuplot [raw gnuplot, gnuplot@prefix]
      set table "$meta" using ($1/\freq@scale):(\plot@macro);
      set table \
      plot "$meta" using ($1/\freq@scale):(\plot@macro);
  \fi
}
}

\addBodeTFPlot  This macro is designed to issues a single \addplot macros for the set of coefficients and delay. All of the work is done by the \build@TF@plot macro.
\newcommand{\addBodeTFPlot}[3][thick]{
\gdef\plot@macro{}
\gdef\temp@macro{}
\ifnum\pdf@strcmp{#2}{phase}=0
  \build@TF@plot{\temp@macro}{\plot@macro}{#3}
\else
  \build@TF@plot{\plot@macro}{\temp@macro}{#3}
\fi
\edef\supplied@domain{\pgfkeysvalueof{/pgfplots/domain}}
\edef\domain@start{\expandafter\get@interval@start\supplied@domain\@nil}
\edef\domain@end{\expandafter\get@interval@end\supplied@domain\@nil}
\if@pgfarg
  \edef\temp@cmd{\noexpand\addplot [freq@filter, domain=\domain@start:\domain@end, variable=t, thick, \opt]
      \plot@macro;}
  \else
    \edef\temp@cmd{\noexpand\addplot [variable=t, thick, \opt]
      \plot@macro;}
  \fi
\edef\temp@cmd{\noexpand\addplot [freq@filter, domain=\domain@start:\domain@end, variable=t, \opt]
      \plot@macro;}
\edef\temp@cmd{\noexpand\addplot [variable=t, \opt]
      gnuplot [raw gnuplot, gnuplot@prefix]
      set table "$meta" using ($1/\freq@scale):(\plot@macro):(\plot@macro);
      set table \
      plot "$meta" using ($1/\freq@scale):(\plot@macro);
  \fi
}
\addBodeComponentPlot This macro is designed to issue a single \addplot macro capable of plotting linear combinations of the basic components described in Section 3.1.1. The only work to do here is to handle the \pgf package option.

\newcommand{\addBodeComponentPlot}[2][thick]{
  \edef\supplied@domain{\pgfkeysvalueof{/pgfplots/domain}}
  \edef\domain@start{\expandafter\get@interval@start\supplied@domain\@nil}
  \edef\domain@end{\expandafter\get@interval@end\supplied@domain\@nil}
  \if@pgfarg
    \addplot [freq@filter, domain=\domain@start*freq@scale:domain@end*freq@scale, variable=t, #1] {\plot@macro};
  \else
    \stepcounter{gnuplot@id}
    \ifnum\pdf@strcmp{#2}{phase}=0
      \addplot [variable=t, #1] gnuplot [raw gnuplot, gnuplot@prefix]
      { set table $meta;
        set dummy t;
        set logscale x 10;
        set xrange [\domain@start*freq@scale:domain@end*freq@scale];
        set samples \pgfkeysvalueof{/pgfplots/samples};
        plot '+' using (t) : ((\plot@macro)/(\ph@scale)) smooth unwrap;
        set table "\bodeplot@prefix\arabic{gnuplot@id}.table";
        plot "$meta" using ($1/(\freq@scale)):(\ph@scale);
      };
    \else
      \addplot [variable=t, #1] gnuplot [raw gnuplot, gnuplot@prefix]
      { set table $meta;
        set dummy t;
        set logscale x 10;
        set xrange [\domain@start*freq@scale:domain@end*freq@scale];
        set samples \pgfkeysvalueof{/pgfplots/samples};
        plot \plot@macro;
        set table "\bodeplot@prefix\arabic{gnuplot@id}.table";
        plot "$meta" using ($1/(\freq@scale)):(\ph@scale);
      };
    \fi
  \fi
}

BodePhPlot (env.) An environment to host phase plot macros that pass parametric functions to \addplot macros. Uses the defaults specified in \bode@style to create a shortcut that includes the \tikzpicture and \semilogaxis environments.

\newenvironment{BodePhPlot}[3][3]{{
  \parseenv@opt{#1}
  \edef\temp@cmd{\noexpand\begin{tikzpicture} \unexpanded{\expandafter{\opt@tikz}}}
  \if\pgfarg
    \addplot [freq@filter, domain=\domain@start*freq@scale:domain@end*freq@scale, variable=t, #1] #2;
  \else
    \addplot [variable=t, #1] gnuplot [raw gnuplot, gnuplot@prefix]
    { set table $meta;
      set dummy t;
      set logscale x 10;
      set xrange [\domain@start*freq@scale:domain@end*freq@scale];
      set samples \pgfkeysvalueof{/pgfplots/samples};
      plot #2;
      set table "\bodeplot@prefix\arabic{gnuplot@id}.table";
      plot "$meta" using ($1/(\freq@scale)):(\ph@scale);
    };
  \fi
}}
BodeMagPlot \texttt{(env.)} An environment to host magnitude plot macros that pass parametric functions to \texttt{addplot} macros. Uses the defaults specified in \texttt{bode@style} to create a shortcut that includes the \texttt{tikzpicture} and \texttt{semilogaxis} environments.

\begin{verbatim}
\newenvironment{BodeMagPlot}[3][]{
  \parse@env@opt{#1}
  \edef\temp@cmd{\noexpand\begin{tikzpicture} \unexpanded\expandafter{\opt@tikz}}
  \noexpand\begin{semilogaxis}[bode@style,freq@label,xmin={#2},xmax={#3},
domain=#2:#3,height=2.5cm,\unexpanded\expandafter{\opt@axes}}}
}{\temp@cmd}
\end{tikzpicture}}
\end{verbatim}

BodePlot \texttt{(env.)} Same as \texttt{BodeMagPlot}. The \texttt{BodePlot} environment is deprecated as of v1.1.0, please use the \texttt{BodePhPlot} and \texttt{BodeMagPlot} environments instead.

\begin{verbatim}
\newenvironment{BodePlot}[3][]{
  \parse@env@opt{#1}
  \edef\temp@cmd{\noexpand\begin{tikzpicture} \unexpanded\expandafter{\opt@tikz}}
  \noexpand\begin{semilogaxis}[bode@style,freq@label,xmin={#2},xmax={#3},
domain=#2:#3,height=2.5cm,\unexpanded\expandafter{\opt@axes}}}
}{\temp@cmd}
\end{tikzpicture}}
\end{verbatim}
### 4.4.2 Internal macros

\add@feature This is an internal macro to add a basic component (pole, zero, gain, or delay), described using one of the macros in Section 3.1.1 (input #2), to a parametric function stored in a global macro (input #1). The basic component value (input #3) is a complex number of the form \(\{\text{re}, \text{im}\}\). If the imaginary part is missing, it is assumed to be zero. Implementation made possible by this StackExchange answer.

\newcommand*{\add@feature}[3]{\ifcat$\detokenize\expandafter{#1}$\else\xdef#1{\unexpanded\expandafter{#1 0 +#2}}\fi\foreach \y [count=\n] in #3 {\xdef#1{\unexpanded\expandafter{#1 + \n}}\xdef\Last@LoopValue{\n}}\fi\ifnum\Last@LoopValue=1\xdef#1{\unexpanded\expandafter{#1}{0}}\fi}

\build@ZPK@plot This is an internal macro to build parametric Bode magnitude and phase plots by concatenating basic component (pole, zero, gain, or delay) macros (Section 3.1.1) to global magnitude and phase macros (inputs #1 and #2). The \add@feature macro is used to do the concatenation. The basic component macros are inferred from a \texttt{feature/values} list, where \texttt{feature} is one of \texttt{z,p,k,d}, for zeros, poles, gain, and delay, respectively, and \texttt{values} is a comma separated list of comma separated lists (complex numbers of the form \(\{\text{re}, \text{im}\}\)). If the imaginary part is missing, it is assumed to be zero.

\newcommand*{\build@ZPK@plot}[4]{\foreach \feature/\values in {#4} {\ifnum\pdf@strcmp{\feature}{z}=0\foreach \z in \values {\ifnum\pdf@strcmp{#3}{linear}=0\add@feature{#2}{\PhZeroLin}{\z}\add@feature{#1}{\MagZeroLin}{\z}\else\ifnum\pdf@strcmp{#3}{asymptotic}=0\add@feature{#2}{\PhZeroAsymp}{\z}\add@feature{#1}{\MagZeroAsymp}{\z}\else\add@feature{#2}{\PhZero}{\z}\add@feature{#1}{\MagZero}{\z}\fi\fi}}\fi\ifnum\pdf@strcmp{\feature}{p}=0\foreach \p in \values {\ifnum\pdf@strcmp{#3}{linear}=0\add@feature{#2}{\PhPoleLin}{\p}\add@feature{#1}{\MagPoleLin}{\p}\else\ifnum\pdf@strcmp{#3}{asymptotic}=0\add@feature{#2}{\PhPoleAsymp}{\p}\add@feature{#1}{\MagPoleAsymp}{\p}\else\add@feature{#2}{\PhPole}{\p}\add@feature{#1}{\MagPole}{\p}\fi\fi}}}
This is an internal macro to build parametric Bode magnitude and phase functions by computing the magnitude and the phase given numerator and denominator coefficients and delay (input #3). The functions are assigned to user-supplied global magnitude and phase macros (inputs #1 and #2).
\parse@opt Parses options supplied to the main Bode macros. A for loop over tuples of the form \obj/\typ/\opt with a long list of nested if-else statements does the job. If the input \obj is plot, axes, group, approx, or tikz the corresponding \opt are passed, unexpanded, to the addplot macro, the nextgroupplot macro, the groupplot environment, the buildZPK@plot macro, and the tikzpicture environment, respectively. If \obj is commands, the corresponding \opt are stored, unexpanded, in the macros \optph@commands and \optmag@commands, to be executed in appropriate axis environments.

\newcommand{\parse@opt}[1]{
  \gdef\optmag@axes{}
  \gdef\optph@axes{}
  \gdef\optph@plot{}
  \gdef\optmag@plot{}
  \gdef\opt@group{}
  \gdef\opt@approx{}
  \gdef\optph@commands{}
  \gdef\optmag@commands{}
  \gdef\opt@tikz{}
  \foreach \obj/\typ/\opt in {#1} {
    \ifnum\pdf@strcmp{\unexpanded\expandafter{\obj}}{plot}=0
    \ifnum\pdf@strcmp{\unexpanded\expandafter{\typ}}{mag}=0
      \gdef\optmag@axes{\unexpanded\expandafter{\plot}}
    \else
      \gdef\optph@axes{\unexpanded\expandafter{\plot}}
    \fi
    \fi
    \gdef\optph@plot{}
    \gdef\optmag@plot{}
    \gdef\opt@group{}
    \gdef\opt@approx{}
    \gdef\optph@commands{}
    \gdef\optmag@commands{}
    \gdef\opt@tikz{}
    \foreach \obj/\typ/\opt in {#1} {
      \ifnum\pdf@strcmp{\unexpanded\expandafter{\obj}}{plot}=0
        \ifnum\pdf@strcmp{\unexpanded\expandafter{\typ}}{mag}=0
          \gdef\optmag@axes{\unexpanded\expandafter{\plot}}
        \else
          \gdef\optph@axes{\unexpanded\expandafter{\plot}}
        \fi
      \fi
      \gdef\optph@plot{}
      \gdef\optmag@plot{}
      \gdef\opt@group{}
      \gdef\opt@approx{}
      \gdef\optph@commands{}
      \gdef\optmag@commands{}
      \gdef\opt@tikz{}
    \}
\parse@env@opt \parses options supplied to the Bode, Nyquist, and Nichols environments. A for loop over tuples of the form \obj/\opt, processed using nested if-else statements does the job. The input \obj should either be axes or tikz, and the corresponding \opt are passed, unexpanded, to the axis environment and the tikzpicture environment, respectively.

\newcommand{\parse@env@opt}{1}{
\gdef\opt@axes{}
\gdef\opt@tikz{}
\foreach \obj/\opt in {#1} {
\ifnum\pdf@strcmp{\unexpanded\expandafter{\obj}}{axes}=0
\xdef\opt@axes{\unexpanded\expandafter{\opt}}
\else
\xdef\opt@tikz{\unexpanded\expandafter{\opt}}
\fi
}
4.5 Nyquist plots

4.5.1 User macros

\NyquistZPK \NyquistTF

\NyquistZPK Converts magnitude and phase parametric functions built using \build@ZPK@plot into real part and imaginary part parametric functions. A plot of these is the Nyquist plot. The parametric functions are then plotted in a \tikzpicture environment using the \addplot macro. Unless the package is loaded with the option pgf, the parametric functions are evaluated using gnuplot. A large number of samples is typically needed to get a smooth plot because frequencies near 0 result in plot points that are very close to each other. Linear frequency sampling is unnecessarily fine near zero and very coarse for large \(\omega\). Logarithmic sampling makes it worse, perhaps inverse logarithmic sampling will help, pull requests to fix that are welcome!

\newcommand{\NyquistZPK}[4][]{
\parse@N@opt{#1}
\gdef\func@mag{}
\gdef\func@ph{}
\edef\temp@cmd{\noexpand\begin{tikzpicture} \unexpanded{\opt@tikz}}
\temp@cmd
\build@ZPK@plot{\func@mag}{\func@ph}{\opt@axes}{#2}
\edef\temp@cmd{\noexpand\begin{axis}\bode@style,domain=#3*\freq@scale:#4*\freq@scale,height=5cm,xlabel={$\Re$},ylabel={$\Im$},samples=500,\unexpanded{\opt@axes}}
\temp@cmd
\addplot [only marks,mark=+,thick,red] (-1 , 0);
\edef\temp@cmd{\noexpand\addplot [variable=t, thick, \unexpanded{\opt@plot}]}\if@pgfarg\temp@cmd ( \n@pow{10}{((\func@mag)/20)}*\n@pow{10}{((\func@mag)/20)}*\cos((\func@ph)/(\ph@scale)), \n@pow{10}{((\func@mag)/20)}*\n@pow{10}{((\func@mag)/20)}*\sin((\func@ph)/(\ph@scale)) ) ); \opt@commands\else\stepcounter{gnuplot@id}\temp@cmd gnuplot [parametric, gnuplot@prefix] \{ \n@pow{10}{((\func@mag)/20)}*\cos((\func@ph)/(\ph@scale)), \n@pow{10}{((\func@mag)/20)}*\sin((\func@ph)/(\ph@scale)) \}; \opt@commands\fi\end{axis} \end{tikzpicture}}

\NyquistTF Implementation of this macro is very similar to the \NyquistZPK macro above. The only difference is a slightly different parsing of the mandatory arguments via
\texttt{\addNyquistZPKPlot} adds Nyquist plot of a transfer function in ZPK form. This macro is designed to pass two parametric function to an \texttt{addplot} macro. The parametric functions for phase ($\func@ph$) and magnitude ($\func@mag$) are built using the \texttt{\build@ZPK@plot} macro, converted to real and imaginary parts and passed to \texttt{addplot} commands.

\begin{verbatim}
\newcommand{\NyquistTF}[4][]{
  \parse@N@opt{#1}
  \gdef\func@mag{}
  \gdef\func@ph{}
  \edef\temp@cmd{\noexpand\begin{tikzpicture} \expanded{\opt@tikz}}
  \temp@cmd
  \build@TF@plot{\func@mag}{\func@ph}{#2}
  \edef\temp@cmd{\noexpand\begin{axis} [\bode@style,}
  \domain=#3*\freq@scale:#4*\freq@scale,\height=5cm,\xlabel={$\Re$},\ylabel={$\Im$},\samples=500,\unexpanded{\expandafter{\opt@axes}}
  \temp@cmd
  \addplot [only marks, mark=+, thick, red] (-1 , 0);
  \edef\temp@cmd{\noexpand\addplot [variable=t, thick, \unexpanded{\expandafter{\opt@plot}}]
    \if@pgfarg
      \temp@cmd ( {\n@pow{10}{((\func@mag)/20)}*\cos((\func@ph)/\ph@scale)},
        {\n@pow{10}{((\func@mag)/20)}*\sin((\func@ph)/\ph@scale))} )
    \else
      \stepcounter{gnuplot@id}
      \temp@cmd gnuplot [parametric, gnuplot@prefix] {
        {\n@pow{10}{((\func@mag)/20)}*\cos((\func@ph)/\ph@scale)),
          {\n@pow{10}{((\func@mag)/20)}*\sin((\func@ph)/\ph@scale))
    \opt@commands
    \else
      \addplot [only marks, mark=+, thick, red] (-1 , 0);
      \edef\temp@cmd{\noexpand\addplot [variable=t, thick, \unexpanded{\expandafter{\opt@plot}}]
        \if@pgfarg
          \temp@cmd ( {\n@pow{10}{((\func@mag)/20)}*\cos((\func@ph)/\ph@scale)},
            {\n@pow{10}{((\func@mag)/20)}*\sin((\func@ph)/\ph@scale))
        \else
          \stepcounter{gnuplot@id}
          \temp@cmd gnuplot [parametric, gnuplot@prefix] {
            {\n@pow{10}{((\func@mag)/20)}*\cos((\func@ph)/\ph@scale)),
              {\n@pow{10}{((\func@mag)/20)}*\sin((\func@ph)/\ph@scale))
        \opt@commands
        \fi
      \end{axis}
      \end{tikzpicture}}
\}
\addNyquistZPKPlot
\end{verbatim}

\texttt{\addNyquistZPKPlot} adds Nyquist plot of a transfer function in ZPK form. This macro is designed to pass two parametric function to an \texttt{addplot} macro. The parametric functions for phase ($\func@ph$) and magnitude ($\func@mag$) are built using the \texttt{\build@ZPK@plot} macro, converted to real and imaginary parts and passed to \texttt{addplot} commands.

\begin{verbatim}
\newcommand{\NyquistZPKPlot}[2][]{
  \gdef\func@mag{}
  \gdef\func@ph{}
  \build@ZPK@plot{\func@mag}{\func@ph}{#2}
  \edef\supplied@domain{\pgfkeysvalueof{/pgfplots/domain}}
  \edef\domain@start{\expandafter{\get@interval@start}\supplied@domain@nil}
  \edef\domain@end{\expandafter{\get@interval@end}\supplied@domain@nil}
  \if@pgfarg
    \addplot [domain=\domain@start*\freq@scale:\domain@end*\freq@scale, variable=t, #1] ( {\n@pow{10}{((\func@mag)/20)}*\cos((\func@ph)/\ph@scale)},
      {\n@pow{10}{((\func@mag)/20)}*\sin((\func@ph)/\ph@scale)) )
  \else
    \stepcounter{gnuplot@id}
    \addplot [domain=\domain@start*\freq@scale:\domain@end*\freq@scale, variable=t, #1] gnuplot [parametric, gnuplot@prefix] {
      {\n@pow{10}{((\func@mag)/20)}*\cos((\func@ph)/\ph@scale))},
        {\n@pow{10}{((\func@mag)/20)}*\sin((\func@ph)/\ph@scale))};
  \fi
}\end{verbatim}
\addNyquistTFPlot\quad Add\s\s\space Nyquist\s\s\space plot\s\s\space of\s\s\space a\s\s\space transfer\s\s\space function\s\s\space in\s\s\space TF\s\s\space form.\s\s\s\space This\s\s\space macro\s\s\space is\s\s\space designed\s\s\space to\s\s\space pass\s\s\space two\s\s\space parametric\s\s\space functions\s\s\space to\s\s\space an\s\s\space \addplot\s\s\space macro.\s\s\s\space The\s\s\space parametric\s\s\space functions\s\s\space for\s\s\space phase\s\s\s\s\space (\func@ph)\s\s\space and\s\s\space magnitude\s\s\s\s\space (\func@mag)\s\s\space are\s\s\space built\s\s\space using\s\s\space the\s\s\space \build@TF@plot\s\s\space macro,\s\s\space converted\s\s\space to\s\s\space real\s\s\space and\s\s\space imaginary\s\s\space parts\s\s\space and\s\s\space passed\s\s\space to\s\s\space \addplot\s\s\space commands.\n
\begin{verbatim}
\newcommand{\addNyquistTFPlot}[2][]{
    \gdef\func@mag{
        \edef\supplied@domain{\pgfkeysvalueof{/pgfplots/domain}}
        \edef\domain@start{\expandafter\get@interval@start\supplied@domain\@nil}
        \edef\domain@end{\expandafter\get@interval@end\supplied@domain\@nil}
        \if@pgfarg
            \addplot [domain=\domain@start*\freq@scale:\domain@end*\freq@scale, variable=t, #1] (\@pow{10}{((\func@mag)/20)}*\cos((\func@ph)/(\ph@scale)), \@pow{10}{((\func@mag)/20)}*\sin((\func@ph)/(\ph@scale)));
        \else
            \stepcounter{gnuplot@id}
            \addplot [domain=\domain@start*\freq@scale:\domain@end*\freq@scale, variable=t, #1] gnuplot [parametric, gnuplot@prefix]{
                \@pow{10}{((\func@mag)/20)}*\cos((\func@ph)/(\ph@scale)),
                \@pow{10}{((\func@mag)/20)}*\sin((\func@ph)/(\ph@scale))};
        \fi
    }
}
\end{verbatim}

\textbf{NyquistPlot}\quad An\s\s\space environment\s\s\space to\s\s\space host\s\s\space \addNyquist...\s\s\space macros\s\s\space that\s\s\space pass\s\s\space parametric\s\s\space functions\s\s\space to\s\s\space \addplot.\s\s\s\space Uses\s\s\space the\s\s\space defaults\s\s\space specified\s\s\space in\s\s\space bode@style\s\s\space to\s\s\space create\s\s\space a\s\s\space shortcut\s\s\space that\s\s\space includes\s\s\space the\s\s\space \tikzpicture\s\s\space and\s\s\space axis\s\s\space environments.\n
\begin{verbatim}
\newenvironment{NyquistPlot}[3][]{
    \parse@env@opt{\@env}
    \edef\temp@cmd{\noexpand\begin{tikzpicture} \unexpanded{\opt@tikz}\end{tikzpicture}}
    \noexpand\begin{axis}[\bode@style, height=5cm, domain=#2:#3, xlabel={$\Re$}, ylabel={$\Im$}, \unexpanded{\opt@axes}\end{axis}}
    \temp@cmd
}{\end{axis}\end{tikzpicture}}
\end{verbatim}

\textbf{4.5.2 Internal commands}

\textbf{\parse@N@opt}\quad Parses options supplied to the main Nyquist and Nichols macros.\s\s\space A\s\s\space for\s\s\space loop\s\s\space over\s\s\space tuples\s\s\space of\s\s\space the\s\s\space form\s\s\space \obj/\opt,\s\s\space processed\s\s\space using\s\s\space nested\s\s\space if-else\s\s\space statements\s\s\space does\s\s\space the\s\s\space job.\s\s\space If\s\s\space the\s\s\space input\s\s\space \obj\s\s\space is\s\s\space plot,\s\s\space axes,\s\s\space or\s\s\space tikz\s\s\space then\s\s\space the\s\s\space corresponding\s\s\space \opt\s\s\space are\s\s\space passed,\s\s\space unexpanded,\s\s\space to\s\s\space the\s\s\space \addplot\s\s\space macro,\s\s\space the\s\s\space axis\s\s\space environment,\s\s\space and\s\s\space the\s\s\space \tikzpicture\s\s\space environment,\s\s\space respectively.\n
\begin{verbatim}
\newcommand{\parse@N@opt}[1][]{
    \gdef\opt@axes{}
    \gdef\opt@plot{}
    \gdef\opt@commands{}
    \gdef\opt@tikz{}
    \foreach \obj/\opt in {#1} {
        \ifnum\pdf@strcmp{\unexpanded{\opt}}{axes}=0
            \addplot [only marks,mark=+,thick,red] (-1 , 0);
        \fi
    }
}
\end{verbatim}
4.6 Nichols charts

These macros and the \texttt{NicholsChart} environment generate Nichols charts, and they are implemented similar to their Nyquist counterparts.

\begin{Verbatim}
\newcommand{\NicholsZPK}[4][{}]{
\parse@N@opt{#1}
\gdef\func@mag{}
\gdef\func@ph{}
edef\temp@cmd{\begin{tikzpicture}\unexpanded\expandafter{\opt@tikz}}
\temp@cmd
\build@ZPK@plot{\func@mag}{\func@ph}{#2}{#3}{#4}
\edef\temp@cmd{\begin{axis}\unexpanded\expandafter{\opt@axes}}
\temp@cmd
\edef\temp@cmd{\addplot [variable=t,thick,\unexpanded\expandafter{\opt@plot}]}
\if@pgfarg
\temp@cmd ( {\func@ph} , {\func@mag} );
\opt@commands
\else
\stepcounter{gnuplot@id}
\temp@cmd gnuplot [raw gnuplot, gnuplot=prefix]
{ set table $meta;
 set logscale x 10;
 set dummy t;
 set samples \pgfkeysvalueof{/pgfplots/samples};
 set trange [\#3*\freq@scale:\#4*\freq@scale];
 plot '+' using (\func@mag) : ((\func@ph)/(\ph@scale));
 unset logscale x;
 set table "$bodeplot@prefix\arabic{gnuplot@id}.table";
 plot "$\$meta" using ($2*\ph@scale):($1);
}
\opt@commands
\fi
\end{axis}
\end{tikzpicture}}
\end{Verbatim}
\newcommand{\NicholsTF}[4][4][]{
\parse@N@opt{#1}
\gdef\func@mag{}
\gdef\func@ph{}
\edef\temp@cmd{\noexpand\begin{tikzpicture} [\unexpanded\expandafter{\opt@tikz}]}
\temp@cmd
\build@TF@plot{\func@mag}{\func@ph}{#2}
\edef\temp@cmd{\noexpand\begin{axis}[\unexpanded\expandafter{\opt@axes}]
  ph@x@label,
  bode@style,
  domain=#3*\freq@scale:#4*\freq@scale,
  height=5cm,
  ylabel={Gain (dB)},
  samples=500,
  \unexpanded\expandafter{\opt@axes}]
}\temp@cmd
\edef\temp@cmd{\noexpand\addplot [variable=t,thick, \opt@plot]}
\if@pgfarg
\temp@cmd ( {\n@mod{\func@ph}{2*pi*\ph@scale}} , {\func@mag} );
\opt@commands
\else
\stepcounter{gnuplot@id}
\temp@cmd gnuplot [raw gnuplot, gnuplot@prefix] { set table $meta1;
  set logscale x 10;
  set dummy t;
  set samples \pgfkeysvalueof{/pgfplots/samples};
  set trange [#3]*\freq@scale:#4*\freq@scale];
  plot '+' using {\func@mag} : {((\func@ph)/(\ph@scale))};
  unset logscale x;
  set table $meta2;
  plot "$\text{meta1}" using ($1):($2) smooth unwrap;
  set table "$\text{bodeplot@prefix}\arabic{gnuplot@id}.table";
  plot "$\text{meta2}" using ($2*\ph@scale):($1);
};
\opt@commands
\fi
\end{axis}
\end{tikzpicture}
}
\newenvironment{NicholsChart}[3][3][]{
\parse@env@opt{#1}
\edef\temp@cmd{\noexpand\begin{tikzpicture} [\unexpanded\expandafter{\opt@tikz}]}
\temp@cmd
\edef\temp@cmd{\noexpand\addplot [variable=t,thick, \opt@plot]}
\if@pgfarg
\temp@cmd { {\n@mod{\func@ph}{2*pi*\ph@scale}} , {\func@mag} };
\opt@commands
\else
\stepcounter{gnuplot@id}
\temp@cmd gnuplot [raw gnuplot, gnuplot@prefix] { set table $meta1;
  set logscale x 10;
  set dummy t;
  set samples \pgfkeysvalueof{/pgfplots/samples};
  set trange [#3]*\freq@scale:#4*\freq@scale];
  plot '+' using {\func@mag} : {((\func@ph)/(\ph@scale))};
  unset logscale x;
  set table $meta2;
  plot "$\text{meta1}" using ($1):($2) smooth unwrap;
  set table "$\text{bodeplot@prefix}\arabic{gnuplot@id}.table";
  plot "$\text{meta2}" using ($2*\ph@scale):($1);
};
\opt@commands
\fi
\end{axis}
\end{tikzpicture}
}
\newenvironment{NicholsChart}{3}[][]{
\parse@env@opt{#1}
\edef\temp@cmd{\noexpand\begin{tikzpicture} [\unexpanded\expandafter{\opt@tikz}]}
\temp@cmd
\edef\temp@cmd{\noexpand\addplot [variable=t,thick, \opt@plot]}
\if@pgfarg
\temp@cmd { {\n@mod{\func@ph}{2*pi*\ph@scale}} , {\func@mag} };
\opt@commands
\else
\stepcounter{gnuplot@id}
\temp@cmd gnuplot [raw gnuplot, gnuplot@prefix] { set table $meta1;
  set logscale x 10;
  set dummy t;
  set samples \pgfkeysvalueof{/pgfplots/samples};
  set trange [#3]*\freq@scale:#4*\freq@scale];
  plot '+' using {\func@mag} : {((\func@ph)/(\ph@scale))};
  unset logscale x;
  set table $meta2;
  plot "$\text{meta1}" using ($1):($2) smooth unwrap;
  set table "$\text{bodeplot@prefix}\arabic{gnuplot@id}.table";
  plot "$\text{meta2}" using ($2*\ph@scale):($1);
};
\opt@commands
\fi
\end{axis}
\end{tikzpicture}
}
\newcommand{\addNicholsZPKChart}[2][]{
\gdef\func@mag{}
\gdef\func@phase{}
\edef\temp@cmd{\noexpand\begin{axis}[\unexpanded\expandafter{\opt@axes}]
  ph@x@label,
  bode@style,
  domain=#2:#3,
  height=5cm,
  ylabel={Gain (dB)},
  samples=500,
  \unexpanded\expandafter{\opt@axes}]
}\temp@cmd
\edef\temp@cmd{\noexpand\addplot [variable=t,thick, \opt@plot]}
\if@pgfarg
\temp@cmd ( {\n@mod{\func@ph}{2*pi*\ph@scale}} , {\func@mag} );
\opt@commands
\else
\stepcounter{gnuplot@id}
\temp@cmd gnuplot [raw gnuplot, gnuplot@prefix] { set table $meta1;
  set logscale x 10;
  set dummy t;
  set samples \pgfkeysvalueof{/pgfplots/samples};
  set trange [#3]*\freq@scale:#4*\freq@scale];
  plot '+' using {\func@mag} : {((\func@ph)/(\ph@scale))};
  unset logscale x;
  set table $meta2;
  plot "$\text{meta1}" using ($1):($2) smooth unwrap;
  set table "$\text{bodeplot@prefix}\arabic{gnuplot@id}.table";
  plot "$\text{meta2}" using ($2*\ph@scale):($1);
};
\opt@commands
\fi
\end{axis}
\end{tikzpicture}
}
\gdef\func@ph{}
\build@ZPK@plot{\func@mag}{\func@ph}{\#2}
edef\supplied@domain{\pgfkeysvalueof{/pgfplots/domain}}
edef\domain@start{\expandafter\get@interval@start\supplied@domain\@nil}
edef\domain@end{\expandafter\get@interval@end\supplied@domain\@nil}
if\@pgfarg
\addplot [variable=t, domain=\domain@start*\freq@scale:\domain@end*\freq@scale, #1]
  ( \func@ph , \func@mag );
else
stepcounter{gnuplot@id}
\addplot [#1] gnuplot [raw gnuplot, gnuplot@prefix]
{ set table $\$meta$;
  set logscale x 10;
  set dummy t;
  set samples \pgfkeysvalueof{/pgfplots/samples};
  set trange [\domain@start*\freq@scale:\domain@end*\freq@scale];
  plot '+' using (\func@mag) : ((\func@ph)/(\ph@scale));
  unset logscale x;
  set table "$\$bodeplot@prefix\arabic{gnuplot@id}.table$";
  plot "$\$meta$" using ($2*\ph@scale$):(1$);
};
fi
\newcommand{\addNicholsTFChart}[2][2]{
\gdef\func@mag{}
\gdef\func@ph{}
\build@TF@plot{\func@mag}{\func@ph}{\#2}
edef\supplied@domain{\pgfkeysvalueof{/pgfplots/domain}}
edef\domain@start{\expandafter\get@interval@start\supplied@domain\@nil}
edef\domain@end{\expandafter\get@interval@end\supplied@domain\@nil}
if\@pgfarg
\addplot [variable=t, domain=\domain@start*\freq@scale:\domain@end*\freq@scale, #1]
  ( \mod{\func@ph}{2*pi*\ph@scale} , \func@mag );
else
stepcounter{gnuplot@id}
\addplot [#1] gnuplot [raw gnuplot, gnuplot@prefix]
{ set table $\$meta1$;
  set logscale x 10;
  set dummy t;
  set samples \pgfkeysvalueof{/pgfplots/samples};
  set trange [\domain@start*\freq@scale:\domain@end*\freq@scale];
  plot '+' using (\func@mag) : ((\func@ph)/(\ph@scale));
  unset logscale x;
  set table $\$meta2$;
  plot "$\$meta1$" using ($1$):($2$) smooth unwrap;
  set table "$\$bodeplot@prefix\arabic{gnuplot@id}.table$";
  plot "$\$meta2$" using ($2*\ph@scale$):(1$);
};
fi
}

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