

Development of Classical Control Toolbox for the Design and Analysis of Linear Time Invariant (LTI) Systems

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Abstract This work presents a Microsoft excel based control toolbox as a teaching and learning aid for the analysis and design of linear time invariant (LTI) control systems. It employs the visual basic application (VBA) for the Microsoft Excel to implement various procedures and includes a versatile with the full capabilities of the EXCEL spreadsheet engine. The generalized form of the linear time invariant (LTI) System as represented in the frequency domain was used to generate suitable algorithmic procedures that enable a user to deploy tools of classical control. As a result, a control toolbox was developed to generate polar, Nyquist and bode plots, some examples were treated using resulting toolbox. The results obtained provide correct and useful analysis description of the systems considered.

Keywords—: Control toolbox, Linear time invariant (LTI), Graphic-user interface (GUI), visual basic application (VBA) Frequency domain, Nyquist, Microsoft Excel.

I. INTRODUCTION

The analysis and synthesis of control and communication systems play a central role in industry in modern times[1]. These activities have advanced at an astronomical rate with the emergence of high speed and affordable digital computers. The cumbersome packages of the 1960's, 70's and 80's have been consolidated into packages such as MATLAB, MATHCAD and other simulation software. Each package has a kernel and a set of supporting toolboxes that make it possible to conserve resources. While they can be very handy, they are very expensive because of their comparatively specialized user community. This work aims at using an alternative approach that employs the relatively common Excel package and exploits its macro features in Visual Basic Environment to implement a classical control toolbox in the last few years; spreadsheets have become a popular computational tool and a powerful platform for performing engineering calculations [2]. Engineering applications can therefore be automated by using the Visual Basic for Applications (VBA) capability of Ms Excel. VBA is a programming environment developed to work with Microsoft's Office applications (Word, Excel, Access, and PowerPoint)[3]. Most operations that can be performed through the normal use of the Office application can also be automated through programming [4]. With VBA, codes can be written to develop software programmed for specific tasks. In Control System Engineering, after the definition and creation of a system it is possible to analyse its performance in the frequency and time domains and synthesize controllers for the feedback system [5].

II. METHODOLOGY

The generic form of transfer functions was adopted and realized using Microsoft Excel spreadsheet by making use of relevant EXCEL formulae. With spreadsheet manipulations and calculations [6], the generic transfer function of LTI systems was initially implemented manually. This was done to explore the suitability of the Excel package for calculating and generating Bode and Polar plots for typical LTI classical control systems. Having realised this, the next step was the development of a User friendly Graphical Users Interface (GUI) for Bode and Polar Plots extensively using Excel VBA platform. $G(j\omega)$ is a complex number for any angular frequency, ω , so the plot is a plot of complex numbers. The complex number, $G(j\omega)$, depends upon frequency, so frequency is a very important parameter to be used to plot the imaginary part of $G(j\omega)$ against the real part of $G(j\omega)$. For any given system with a transfer function $G(s)$ results in a corresponding $G(j\omega)$ where $G(j\omega)$ satisfies this expression:

$$G(j\omega) = \frac{K \prod_{m=1}^M |(j\omega - z_m)|}{|j\omega|^q \prod_{n=1}^N |(j\omega - p_n)|} e^{j\theta(\omega)} \quad 1$$

Where z_m and p_n are the zeros and poles of the system respectively and K is a constant while M is the number of zeros and N the number of poles such that $m \leq n$ and " q " is the type order of the System. and

$$\theta = \text{Arg} \{G(j\omega)\} = \sum_{m=1}^M \text{Arg} (j\omega - z_m) - \sum_{n=1}^N (j\omega - p_n) - q\pi / 2 \quad 2$$

Each point on the polar plot is represented by an Euler representation consisting of its magnitude and argument [7]. Hence $G(j\omega) = |G(j\omega)|e^{j\theta(\omega)}$

Where $|G(j\omega)|$ is the magnitude of the complex transfer function

$$\theta = \text{Arg}\{G(j\omega)\} = \tan^{-1}\{X(\omega)/R(\omega)\} \tag{3}$$

The transfer function of a system can also be described in the frequency domain by the relation [7]

$$G(j\omega) = G(j\omega)|_{s=j\omega} = R(\omega) + jX(\omega) \tag{4}$$

where $R(\omega)$ and $X(\omega)$ is the real component and imaginary component of the transfer function respectively and $|G(j\omega)|^2 = |X(\omega)|^2 + |R(\omega)|^2$ The results of the data for the required parameters were tabulated in the EXCEL spreadsheet as shown in Table 1.

TABLE 1
Format of the Programme output data generated

	$ G(j\omega) $	$20\log G(j\omega) $	$\text{Arg}(G(j\omega))$ (Degree)	$\text{Re}\{G(j\omega)\} = R(\omega)$	$\text{Im}\{G(j\omega)\} = X(\omega)$

The procedures outlined above were automated with the use of the embedded macros of EXCEL to create a computer software program. Using available functions of the platform, a GUI was designed and developed to facilitate user-friendly interface, with the aim of allowing a user to easily interact with program.

A. Testing of the Developed Program with some LTI systems

The Excel VBA based generation of Polar and Bode plots was tested for different systems and corresponding generated plots were shown sequentially. The experiments were chosen to test the capability of the program to handle some common typical examples. Table 2 shows the transfer functions of the systems used on the program developed. The system parameters captured by the GUI are used by the program as inputs. These inputs are used by the program to generate data that are then plotted to obtain Polar, Nyquist and Bode plots.

TABLE 2
Transfer Functions of Systems Used On The Program Developed

Experiment No	System's characteristic Equation	System Description
1	$G(s) = \frac{1}{0.8s + 1}$	Type 0, One real pole
2	$G(s) = \frac{1 + 0.5s}{1 + s}$	Type 0, One Zero & One real pole
3	$G(s) = \frac{1}{0.8s + 1}$	Type 0, One real pole, with a time delay of 0.5sec

B Experiment One

Consider a simple R-C filter circuit whose transfer function is expressed below:

$$G(j\omega) = \frac{1}{j\omega(RC) + 1}$$

Given $R=100\Omega$ and $C= 8\text{mF}$, $RC = 100 \times 8 \times 10^{-3} = 0.8$

$$G(s) = \frac{1}{0.8s + 1} = \frac{1.25}{s + 1.25} \tag{7}$$

From the above equation, the following system parameters are extracted:

System type order "STO" = 0;

Constant "K" = 1.25; No of Zeros = 0; No of Poles = 1; Poles = -1.25

The system is subjected to angular frequencies from 0 to 600 rad./s to the system and the result obtained is shown in Table 3.

C. Experiment Two

A control system with transfer function expressed below:

$$G(s) = \frac{1+0.5s}{1+s} \quad 8$$

From the above equation, the system parameters are:

System type order “STO” = 0;

Constant “K” = 1; No of Poles = 1 at -1; No of Zero=1 at -2

A range of angular frequencies from 0 to 600 rad./s is used for the system and the result obtained is displayed in Table 4

D. Experiment Three

Obtaining the frequency response of system described by equation 8 when a time delay of 0.5s was introduced.

III RESULTS

A. Results for Experiment One

TABLE 3

: Parameters Displayed by the Program for Experiment One

No of Poles	No of Zeros	System Type Order	Constant	Time Delay
1	0	0	1.25	0
Poles-Real:	-1.25			
Poles-Complex:	0			
Zeros-Real:	0			
Zeros-Complex:	0			

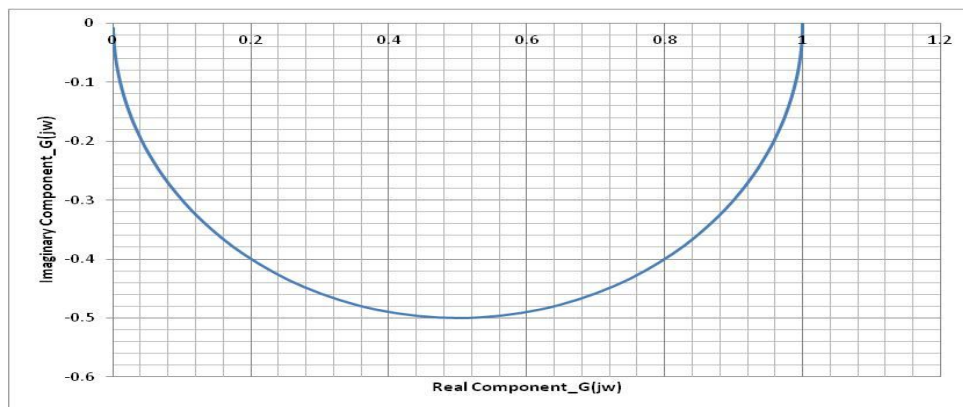


Fig1.a Polar Plot for the Transfer Function 3. (Type 0 system with one pole)

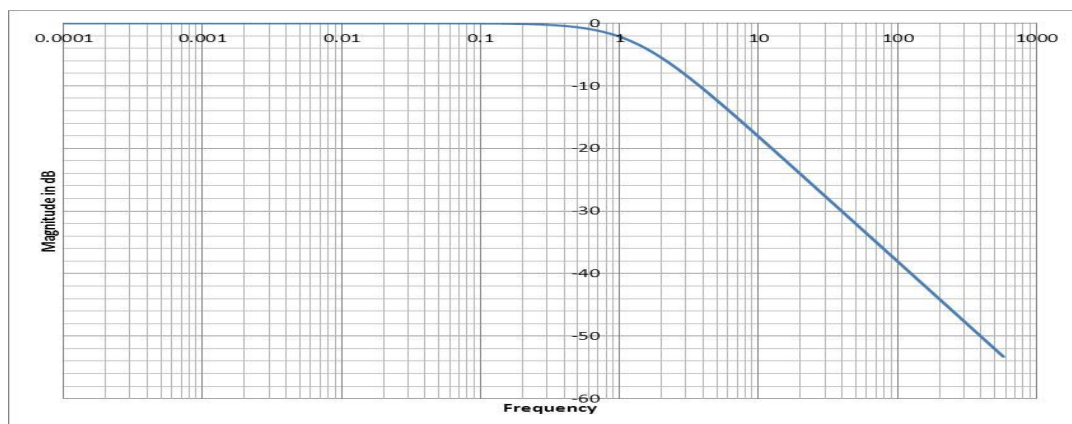


Fig1.b Bode magnitude Plot for Transfer Function 3.(Type 0 system with one pole)

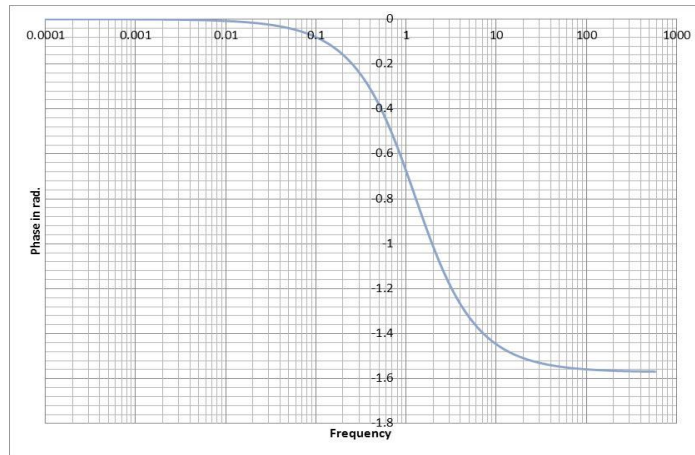


Fig1.c Bode-Phase Plot for Transfer Function 3. (Type 0 system with one pole)

B. Results for Experiment Two

The parameters displayed by the program is as shown in Table 4

TABLE 4

No of Poles	No of Zeros	System Type Order	Constant	Time Delay
1	1	0	10	0
Poles-Real:	-1			
Poles-Complex:	0			
Zeros-Real:	-2			
Zeros-Complex:	0			

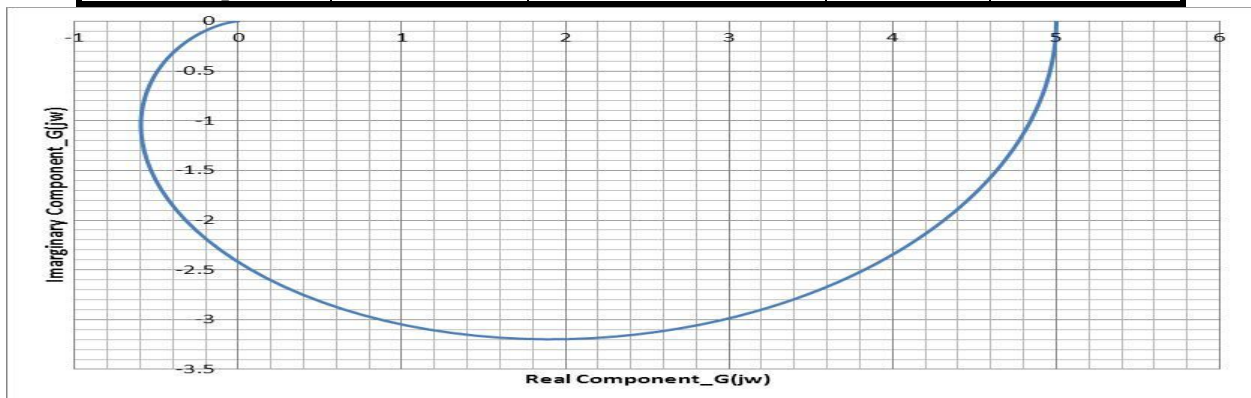


Fig2a Polar Plot for Transfer Function 4 (Type 0 system with one poles & one zero)

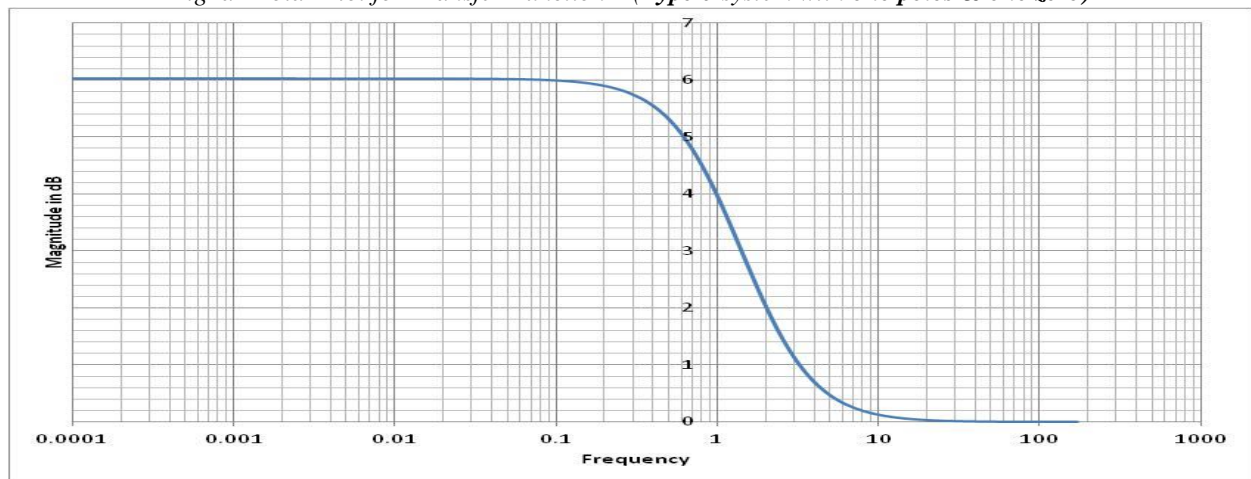


FIG2B BODE MAGNITUDE PLOT FOR TRANSFER FUNCTION 4 (TYPE 0 SYSTEM WITH ONE POLES & ONE ZERO)

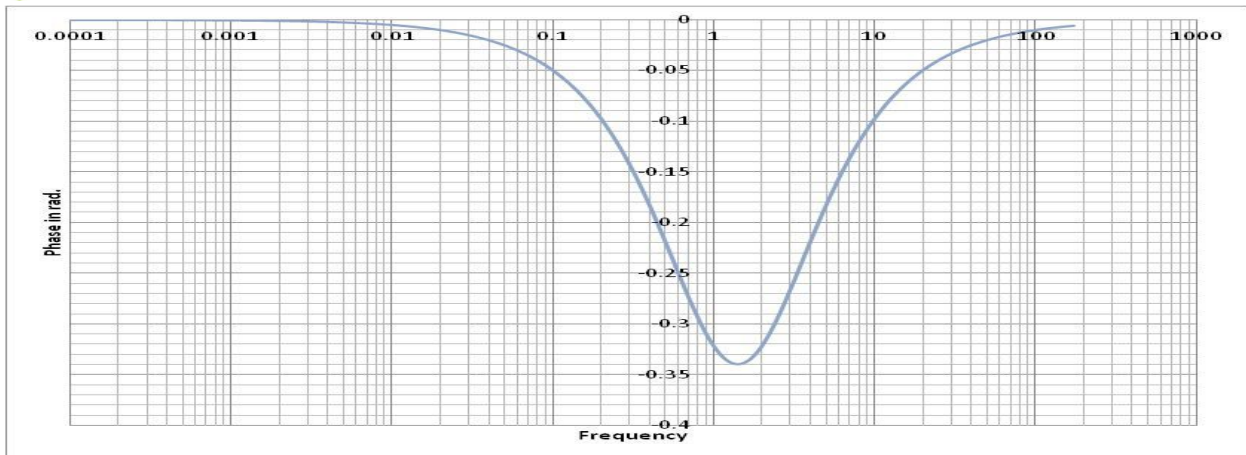


FIG .2C BODE-PHASE PLOT FOR TRANSFER FUNCTION 4 (TYPE 0 SYSTEM WITH ONE POLES & ONE ZERO)

C. Results for Experiment Three

Parameters Displayed by the Program for Experiment Three

TABLE 5

No of Poles	No of Zeros	System Type Order	Constant	Time Delay
1	0	0	1.25	0.15
Poles-Real:	-1.25			
Poles-Complex:	0			
Zeros-Real:	0			
Zeros-Complex:	0			

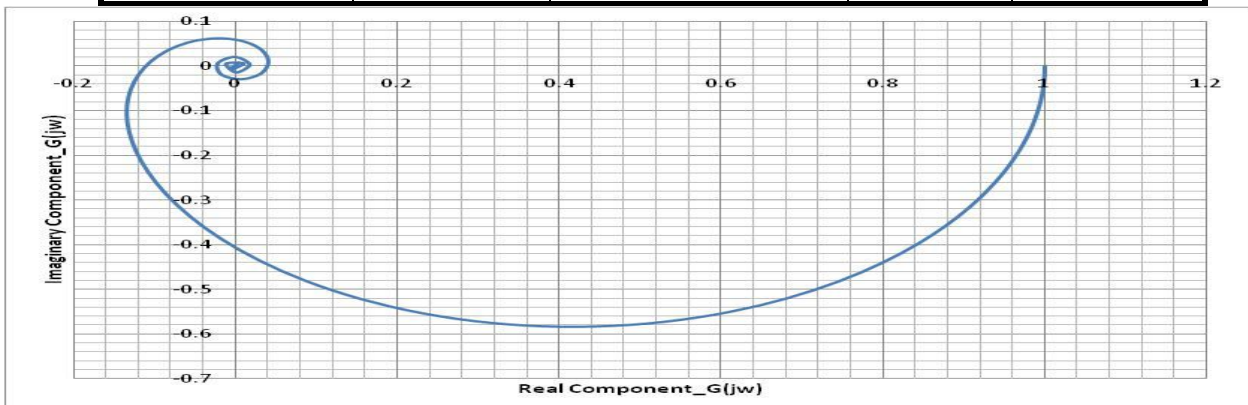


Fig3 a Polar Plot for Transfer Function of Transfer Function 5 (Type 0 system with one pole and a time delay of 0.15s)

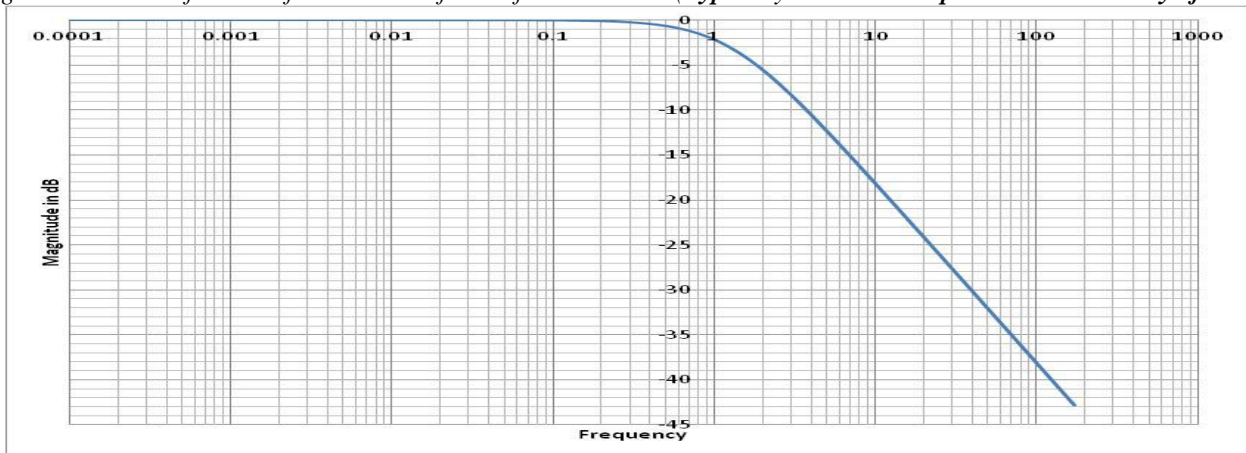


Fig3.b Bode magnitude Plot for Transfer Function 5 (Type 0 system with one pole and a time

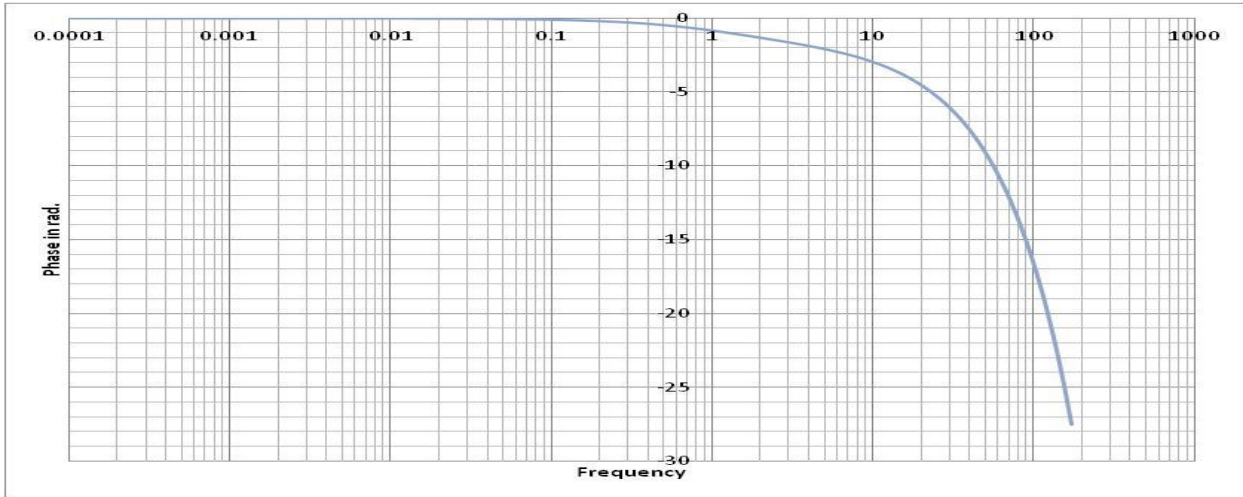


Fig3.c Bode-Phase Plot for Transfer Function 5 (Type 0 system with one pole and a time delay of 0.15s)

IV DISCUSSIONS

The results presented above show the anticipated behaviours of the characteristic equation of the systems described. However, the response of each system to very low angular frequency (that is as ω tends to or becomes 0) is could be observed on the generated frequency response as follows:

For the system described in experiment 1

$$|G(j\omega)| = 1 / |j0.8\omega + 1|$$

As ω becomes 0, therefore

$$|G(j\omega)| = 1$$

This is exactly what was obtained for value generated by the program for Polar plot.

Thus for the Bode – Magnitude plot,

$$20\log_{10} |G(j\omega)| = 20 \log_{10}(1) = 0$$

The phase at this instance is obtained thus:

$$\text{Phase} = \tan^{-1}(0/1) - \tan^{-1}(0.8 * 0/1)$$

$$= 0$$

Repeating the above for characteristic equation for experiments 2 and 3 the following table which summaries the response of each system to very low frequencies was obtained.

TABLE 6
RESPONSE OF SOME OF THE LTI SYSTEMS TO VERY LOW FREQUENCIES

Experiment No	System's characteristic Equation	System Description	As ω tends to 0, $ G(j\omega) =$	Value from the Programme
1	$G(s) = \frac{1}{0.8s + 1}$	Type 0, One real pole	1	1
2	$G(s) = \frac{75}{(s+3)(s+5)}$	Type 0, two real poles	5	5
3	$G(s) = \frac{750}{(s+1)(s+3)(s+5)}$	Type 0, three real poles	50	50

V CONCLUSION

Based on the results obtained, it can be concluded that Bode data, magnitude plot and phase plot for transfer function with varying sinusoidal input frequencies can be generated by implementing VBA codes in Excel. With this achievement, Excel-VBA can be used as an inexpensive alternative to MATLAB for plotting Bode, Polar and Nyquist plots



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