01196C

PROGRAM DESCRIPTION I

Program Title BODE PLOT OF A GENERAL TRANSFER FUNCTION

Contributor's Name Tom Frenock

Address 3122 NW 27th Street

City Gainesville **State/Country** Florida **Zip Code** 32605

Program Description, Equations, Variables This program computes and plots the frequency response of a general transfer function in the form:

$$T(s) = k\,\frac{(s+z_1+jz_1)(s+z_2+jz_2)\ldots(s+z_m+jz_m)}{(s+p_1+jp_1)(s+p_2+jp_2)\ldots(s+p_n+jp_n)}$$

where k is a non-zero real number which takes care of any leading coefficients in the unfactored polynomials. The program can be used with or without the 82143A printer and all operations, except those used exclusively for printing, are operational without the printer.

Highlighted features of this program are subroutines to automatically compute the frequency scale of the plots, compute gain and phase margins, compute magnitude and phase of a single frequency, and offer direct comparison of two plots (useful in system compensation).

The storage requirements are dependent on two variables, the

(continued)

Necessary Accessories At least 2 memory modules (quad recommended) and printer.

Operating Limits and Warnings [1]All frequencies are in rad/s.

[2]Do not assign any USER functions to A,E,or F keys.

[3]ω is displayed on the HP-41C as W.

[4]Set printer to MAN for all operations.

Reference(s) Dorf, Richard C.,Modern Control Systems,Third Edition,Addison-Wesley, Reading, Mass.,1980.

Hamming, Richard W., Introduction to Applied Numerical Analysis, McGraw Hill, 1971.

number of points to be plotted and the size of T(s). A formula for determining the necessary memory is:

$$\text{SIZE} = 18 + 2\,(m + n + \text{STEPS})$$

where STEPS is the number of points to be plotted.This means that if T(s) has 2 finite zeros, 3 poles, and a 25 point plot is desired, 78 memory registers will be required. The maximum number of points to be plotted can be computed from this formula:

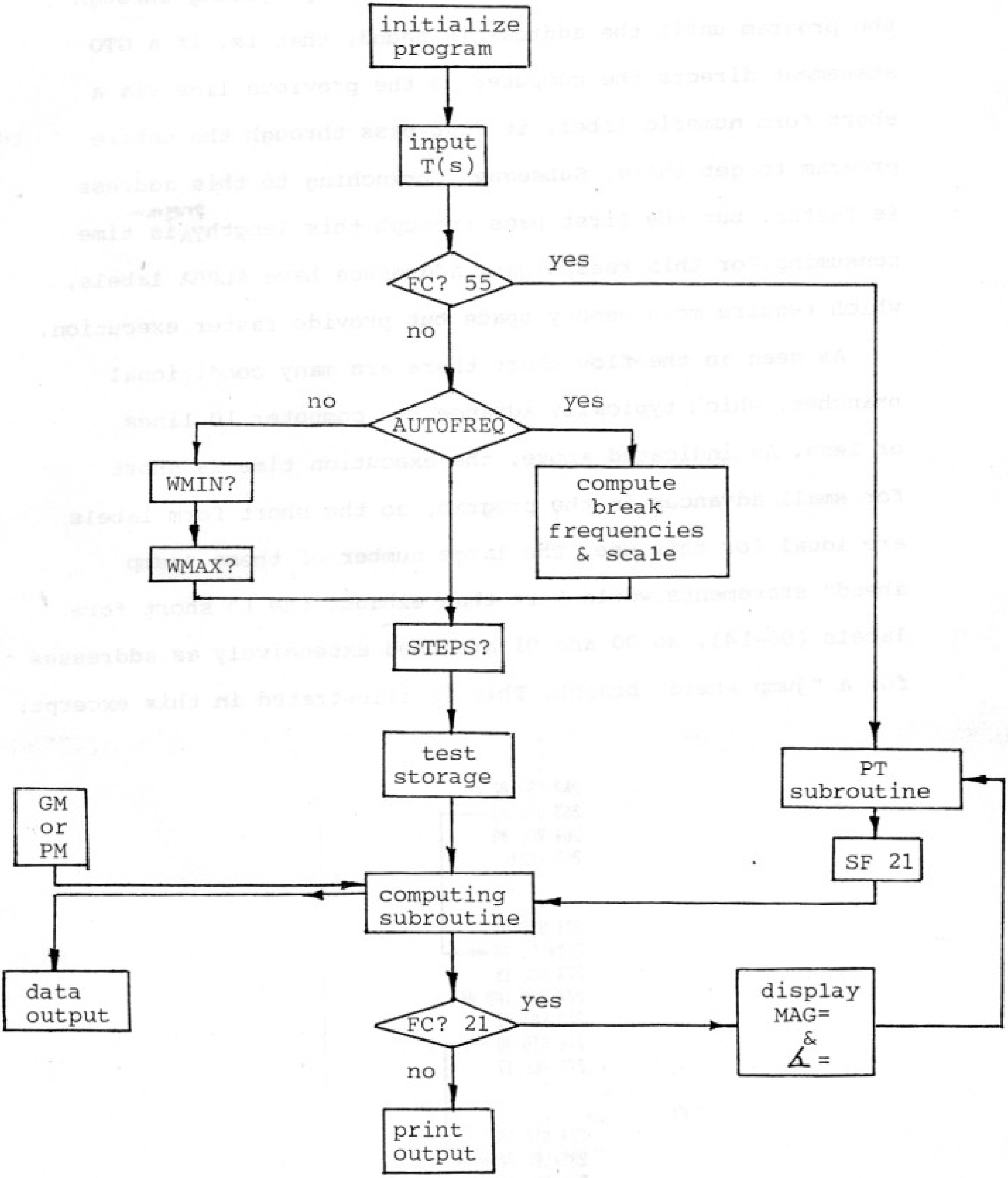
$$\text{STEPS} = \frac{M-2(m+n)-164}{2}$$

where M is the maximum available memory before the program is entered into the calculator. Using the above example, the maximum number of points that can be plotted with an HP-41C that has full memory is 72.

It should be noted that if poles or zeros exist on the $j\omega$ axis in the s plane, the magnitude plot might go to $\pm\infty$dB. These numbers are not computable on a finite machine and 10^{-99} is substituted for zero when division by or logarithm of zero is to occur. The result of this substitution is that the magnitude extremes will be $\pm$ 1980 dB. If one of these singularities is present, it might be overlooked on the magnitude plot because of its discrete nature, but a 180° phase shift will appear on the phase curve. This sudden phase shift is an indicator of the singularity.

Detailed description of this program follows the simplified flow chart, but this reading is not necessary to learn how to use this program. The best way to learn this program is to work the sample problems.

SIMPLIFIED FLOW CHART



NOTE: Caps denote message prompted on the HP-41C display.

LABELS. A good starting point is the subject of label searching (see Appendix G in the HP-41C Owner's Handbook). The calculator looks for numeric labels by cycling through the program until the address is found, that is, if a GTO statement directs the computer to the previous line via a short form numeric label, it must pass through the entire program to get there. Subsequent branching to this address is faster, but the first pass through this lengthy program is time consuming.For this reason many addresses have ALPHA labels, which require more memory space but provide faster execution.

As seen in the flow chart there are many conditional branches, which typically advance the computer 10 lines or less. As indicated above, the execution time is short for small advances in the program, so the short form labels are ideal for this use. The large number of these "jump ahead" statements would more than exhaust the 15 short form labels (00-14), so 00 and 01 are used extensively as addresses for a "jump ahead" branch. This is illustrated in this excerpt:

```
   .
   .
   .
262 FS? 02
263 GTO 00 ──┐
264 RCL 00   │
265 X<>Y     │
   .         │
   .         │
271 STO 01   │
272•LBL 00 ◄─┘
273 RCL 15
274 STO IND 06
275 FS? 02
276 GTO 00 ──┐
277 RCL 17   │
   .         │
   .         │
284 STO 16   │
285•LBL 00 ◄─┘
286 RCL 11
   .
```

Label 00 is used twice here and the computer would branch as the arrows indicate, stopping at the first LBL 00 it comes across. By using this labeling scheme, there are enough short form labels left to address unique locations.

INITIALIZING. Execution of BODE clears all storage registers, sets the USER mode, and initializes a program counter and plotting field width (see the footnote on page 57 of the 82143A Printer Handbook).

INPUT OF T(s). The HP-41C prompts the operator for all of the data in the factored transfer function. It will first display "K=?" for the constant and "M=?" for the order of the numerator, which sets a counter that prompts for the right number of zero terms. These are prompted for by "Z?" for the real part and "JZ?" for the imaginary part. After the zeros are read in the computer prompts "N=?" for the order of the denominator. The poles are read in like the zeros were by prompting the right number of "P?" for the real part and "JP?" for the imaginary part of the poles. It should be noted that if m=0 and/or n=0, indicating no zero and/or pole terms, the HP-41C will progress to the next item.

FREQUENCY SCALING. If the printer is present (flag 55 set the HP-41C prompts "Y AUTOFREQ N" for the operator to select automatic or manual frequency scaling. If flag 55 is clear this operation is bypassed and subroutine PT is accessed.

If automatic frequency scaling is desired, press A located directly under the Y (yes) in the display. The calculator then computes the break frequency of each term in T(s), recording the minimum and maximum, and then computin $\pm$ one decade beyond these limits.

If the operator wishes to manually choose the frequency scale limits, press E located directly under the N (no) in the display. This is useful for expansion of a portion of a response plot. The minimum and maximum frequencies will be prompted for by "W MIN?" and "W MAX?" on the display.

After the scale limits are determined, the calculator prompts "STEPS?" for the number of points to be plotted, then computes a logarithmic scale.

PRINTED OUTPUT. After the computations are completed, the stored data is printed next to its corresponding freq-uency. The units of magnitude is decibels and the units of phase angle is degrees. This data can be matched up directly with the points on the following plots.

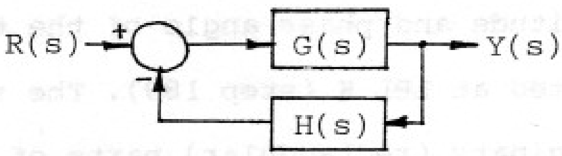
Both plots use the REGPLOT and PRAXIS operations in the printer (see the Printer Handbook, pages 56-59). The hori-zontal axis is at 0 dB on the magnitude plot and at -180^{o} on the phase plot, which is useful on the gain and phase margin calculations.

The field width is 115 dots which gives a plotting accuracy of about 1% ecept on the first and last 3 columns of dots. There is a compression experienced at these limits

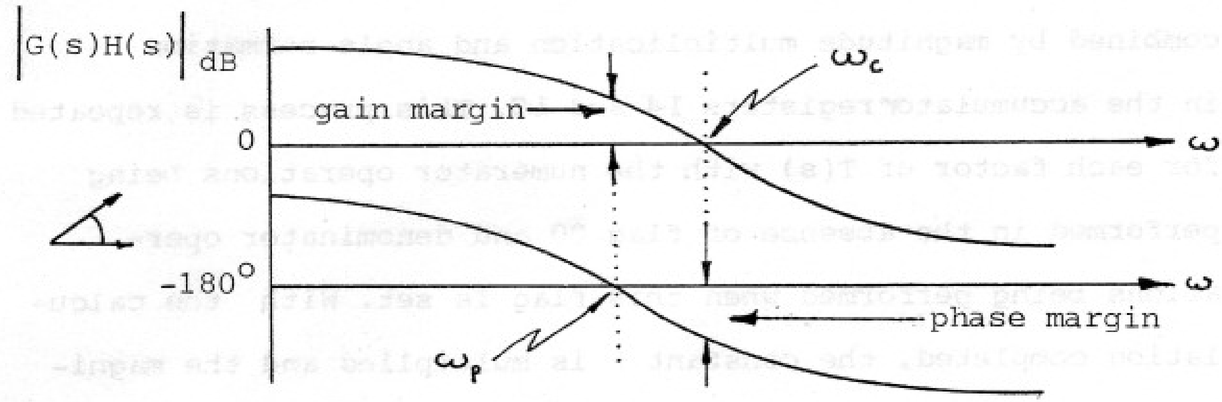
CALCULATIONS. The heart of this program is the subroutine that computes the magnitude and phase angle of the transfer function; this is located at LBL K (step 189). The routine calls the real and imaginary (rectangular) parts of T(s) from memory, adds the frequency to the imaginary part, then converts this complex number to polar notation which is then combined by magnitude multiplication and angle summation in the accumulator registers 14 and 15. This pracess is repeated for each factor of T(s) with the numerator operations being performed in the absence of flag 00 and denominator operations being performed when this flag is set. With the calculation completed, the constant K is multiplied and the magnitude is converted to decibels. A maximum and minimum search is carried out for the scale of the two plots and then the magnitude and angle are stored in memory to later be called for the printed output.

PT SUBROUTINE. If data at only one frequency is needed or one does not have a printer present, this operation provides magnitude data in absolute and decibel units and angle data in degrees. As mentioned before, if the printer is not present, PT will be automatically accessed. Otherwise, execute PT and the calculator will prompt "W=?" for the radian frequency. PT will then branch to the calculation routine and the display the magnitude and angle data on the LCD display only.

GAIN AND PHASE MARGIN. In the closed loop system:



the gain and phase margins can be defined by this graphical representation:



where ω_c is the gain crossover frequency and ω_p is the phase crossover frequency. Both gain and phase margin may be positive or negative. It should also be noted that there may be more than one axis crossing, which is illustrated in problem 2.

PM SUBROUTINE. This computation is based on a linear interpolation of two frequencies and their associated magnitude data as compared to a magnitude of 1.0 (0 dB). The interpolation computes the gain crossover frequency, ω_c, and then computes the magnitude and angle for ω_c. For this computation to work it is necessary to make a linear approximation of an axis crossing, which requires that a small piece of the curve be examined.

To use, execute PM and the HP-41C will prompt "W1?" then

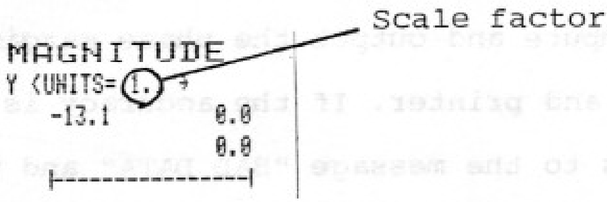
"W2?" for the two frequencies close to ω_c. It should be noted that these frequencies do not have to straddle the axis and one of these should be within one dB of the axis. The calculator then solves for ω_c and its magnitude and angle. The magnitude is checked to be 1.0 ± 0.005 to ensure the phase margin accuracy of 0.1° as displayed. (The accuracy will vary slightly with the slope of the curve as it passes through 0dB. The higher accuracy is obtained with a shallow slope.) If the magnitude is within this range, the calculator will compute and output the phase margin and ω_c to the display and printer. If the accuracy is not met, the program branches to the message "BAD DATA" and the computation need be reinitialized with closer starting frequencies.

<u>GM SUBROUTINE</u>. This routine uses the same program steps as PM but Flag 01 is set, to distinguish which is being computed, and the phase is examined to be $180^\circ \pm 0.005^\circ$. If the accuracy is not met, the program branches to "BAD DATA" and closer frequencies need be entered. These frequencies should be within about one degree of ω_p.

<u>COMP SUBROUTINE</u>. This is used to directly compare two plots by overlaying them and viewing them with the light of a window or desk lamp behind them. This offers the user a direct and accurate way to see how a system compensation affected its frequency response. This comparison depends on the vertical and frequency scales being identical, and the

calculator prompts for all necessary data to provide this requirement.

COMP sets Flag 02 then branches to the begining of the main program and the new (compensated) transfer function is entered. The AUTOFREQ choice is not offered and the minimum and maximum frequencies, dB scale, and angle scale data are prompted for. Other than this, the program operates the same as usual. Care should be exercised in reading the scale factor on a plot. It is not always 1. as shown here.



MISCELLANY. A number of safeguards have been built into this program to prevent time consuming errors. The major ones will be mentioned here.

The flags in the HP-41C are checked throughout this program for printer existence. This ensures that no printer function can be accessed without the connector being inserted. An example of this is if A or E is executed for frequency scaling, the program will branch back to PT and time is not wasted on computing break frequencies or some other unneeded operation.

Another check is to see if enough memory is available before executing the program. If there was not enough memory the HP-41C would keep computing the data until it tried to store something in a ficticious address and then stop execution and display "NONEXISTENT" after several minutes of time. To prevent this situation the SIZE is computed as in the introduction and if the memory space is insufficient execution is halted and the message "SET SIZE nnn." is displayed. The operator can then correct the SIZE to that recommended by the program or larger then press R/S to restart the program.

Another point of interest is that by executing F one can display the frequency in any non-printer operation. This is useful when using PT and the frequency is forgotten. This routine is the same one used by GM and PM to output ω_p and ω_c, respectively.

An anomaly was noticed during an execution of COMP. One plot was made on the end of a roll of paper and the other on a fresh, full roll. When the two plots were aligned on the far left, they were unacceptably misaligned on the far right. This was the only time that any misalignment was ever experienced and this situation should be avoided.

SAMPLE PROBLEMS

1. Compute the Bode plot of a transfer function described by $T(s) = \frac{(s^2+1)}{(s^2+4)(s+2)} = \frac{(s+j)(s-j)}{(s+j2)(s-j2)(s+2)}$.

OPERATION	DISPLAY	COMMENTS
XEQ BODE	K=?	input constant
1 [R/S]	M=?	number of zeros
2 [R/S]	Z?	real part of zero
0 [R/S]	JZ?	imaginary part
1 [R/S]	Z?	
0 [R/S]	Jz?	
-1 [R/S]	N=?	number of poles
3 [R/S]	P?	real part of pole
0 [R/S]	JP?	imaginary part
2 [R/S]	P?	
0 [R/S]	JP?	
-2 [R/S]	P?	
2 [R/S]	JP?	
0 [R/S]	Y AUTOFREQ N	choose auto scaling
A	STEPS?	choose 15 points
15 [R/S]	Outputs printed plots as shown:(next page	

Notice that there is a discontinuity indicating a singularity (in this case, two) around 1.414 rad/s. Now expand this portion of the plot.

press E	W MIN?	
0.9686 [R/S]	W MAX?	
2.065 [R/S]	STEPS?	choose 10 this time
10 [R/S]	Output printed plots (next page)	

Note that there is a 180^{o} phase shift at the singularities.

DATA

FREQ	dB	∠
9.686-01	-40.8	-25.8
1.054+00	-35.5	152.2
1.146+00	-25.9	150.2
1.247+00	-20.3	148.1
1.356+00	-15.9	145.9
1.475+00	-11.7	143.6
1.604+00	-7.3	141.3
1.745+00	-1.9	138.9
1.898+00	7.5	136.5
2.065+00	12.7	-45.9

MAGNITUDE

```
Y (UNITS= 1.) →
      -40.8          12.7
                      0.0
      |-------------|---|
9.7-01 x            :
1.1+00   x          :
1.1+00      x       :
1.2+00        x     :
1.4+00          x   :
1.5+00           x  :
1.6+00             x:
1.7+00              x
1.9+00              :  x
2.1+00              :   x
```

PHASE

```
Y (UNITS= 1.) →
      -180.        152.
      -180.
      |-----------------|
9.7-01|       x
1.1+00|                 x
1.1+00|                 x
1.2+00|                 x
1.4+00|                 x
1.5+00|                 x
1.6+00|                 x
1.7+00|                 x
1.9+00|                 x
2.1+00|      x
```

Now check the data at one of the sinular points, say 1 rad/s.

XEQ PT

W?

insert 1 rad/s

1 [R/S]

MAG=0.0=-1,980.0dB

[R/S]

∠=63.4

Note how the phase shift shows up in the expanded plot.

DATA

FREQ	dB	∠
1.000-01	-18.1	-2.9
1.460-01	-18.2	-4.2
2.132-01	-18.4	-6.1
3.112-01	-18.8	-8.8
4.544-01	-19.8	-12.8
6.634-01	-22.5	-18.4
9.686-01	-40.8	-25.8
1.414+00	-13.8	144.7
2.065+00	12.7	-45.9
3.015+00	-7.1	-56.4
4.401+00	-12.1	-65.6
6.426+00	-15.9	-72.7
9.382+00	-19.3	-78.0
1.370+01	-22.7	-81.7
2.000+01	-26.0	-84.3

MAGNITUDE

```
Y (UNITS= 1.) →
      -40.8          12.7
                      0.0
      |-------------|---|
1.0-01      x       :
1.5-01      x       :
2.1-01      x       :
3.1-01      x       :
4.5-01     x        :
6.6-01    x         :
9.7-01 x            :
1.4+00       x      :
2.1+00              :    x
3.0+00            x :
4.4+00        x     :
6.4+00        x     :
9.4+00      x       :
1.4+01     x        :
2.0+01    x         :
```

PHASE

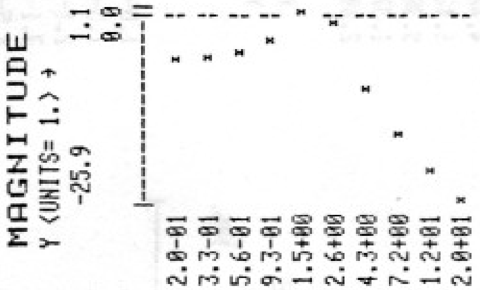
```
Y (UNITS= 1.) →
      -180.        145.
      -180.
      |-----------------|
1.0-01|        x
1.5-01|        x
2.1-01|        x
3.1-01|        x
4.5-01|        x
6.6-01|        x
9.7-01|       x
1.4+00|                 x
2.1+00|     x
3.0+00|    x
4.4+00|    x
6.4+00|   x
9.4+00|   x
1.4+01|   x
2.0+01|   x
```

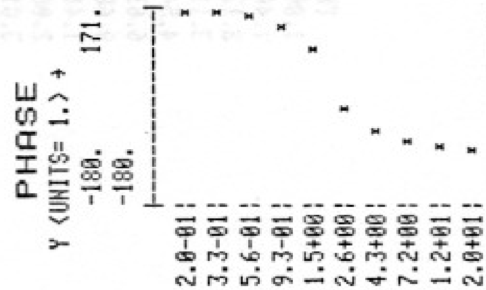
2. Compute the phase margin of $T(s)=\dfrac{s-2}{s^2+s+4}$.

A plot must be made to determine where and how many crossover frequencies occur. Compute this plot like done in problem 1.

DATA

FREQ	dB	∠
2.000-01	-5.9	171.4
3.336-01	-5.7	165.6
5.565-01	-5.1	155.9
9.284-01	-3.4	138.6
1.549+00	1.1	98.2
2.583+00	-1.1	-8.2
4.310+00	-10.1	-48.6
7.189+00	-16.2	-65.9
1.199+01	-21.2	-75.6
2.000+01	-25.9	-81.4



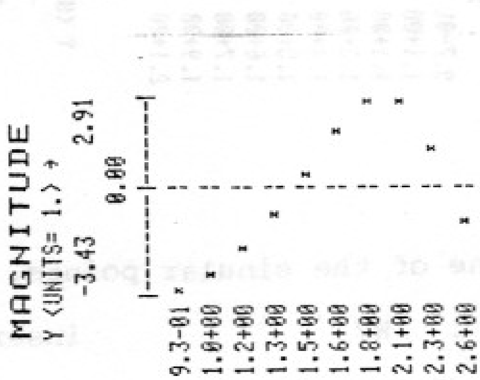


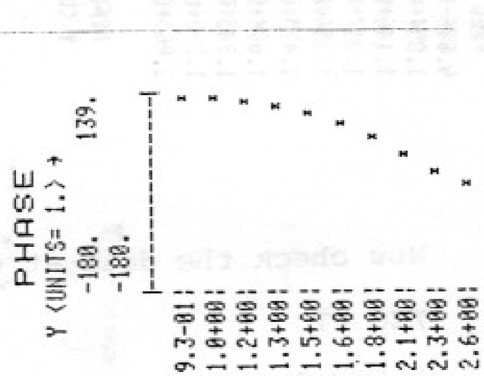
Note that there are 2 axis crossovers. Expand this region as shown then compute the phase margins.

OPERATION	DISPLAY	COMMENTS
Expand as described in problem 1, then:		
XEQ PM	W1?	
1.4 [R/S]	W2?	
1.45 [R/S]	PM=289.5 FREQ=1.4147	nowcompute the other
XEQ PM	W1?	
2.4 [R/S]	W2?	
2.5 [R/S]	PM=180.0 FREQ=2.4495	

DATA

FREQ	dB	∠
9.284-01	-3.4	138.6
1.040+00	-2.8	132.9
1.165+00	-1.9	126.0
1.306+00	-0.9	117.2
1.463+00	0.4	105.7
1.639+00	1.8	89.4
1.837+00	2.9	66.4
2.058+00	2.8	37.8
2.305+00	1.2	11.3
2.583+00	-1.1	-8.2





PM=289.5
FREQ=1.4147

PM=180.0
FREQ=2.4495

011960

3. Compare the open loop response of transfer function

$$G_p(s)H(s) = \frac{10^7}{s(s+10)(s+1000)}$$

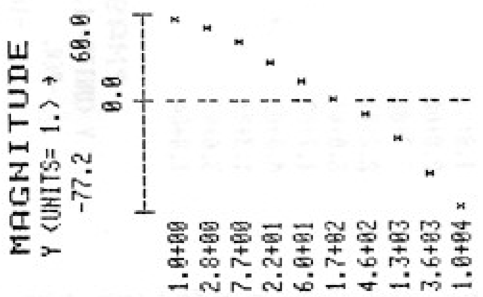
with and without the compensator

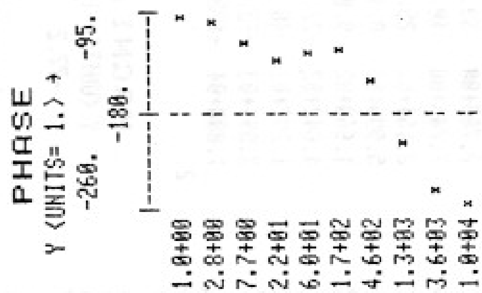
$$G_c(s) = 13.9\,\frac{s+51.3}{s+713}$$ in the form of $G_c(s)G_p(s)H(s)$.

First plot the compensated system response as done in problem 1.

DATA

FREQ	dB	∠
1.000+00	60.0	-94.7
2.783+00	50.8	-102.8
7.743+00	40.3	-120.2
2.154+01	26.5	-135.3
5.995+01	12.5	-129.3
1.668+02	1.4	-126.3
4.642+02	-9.9	-153.0
1.292+03	-27.0	-205.2
3.594+03	-51.0	-243.9
1.000+04	-77.2	-260.4





Now plot the uncompensated system $G_p(s)H(s)$ by doing the following:

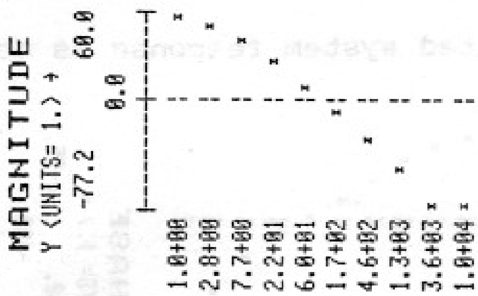
OPERATION	DISPLAY	COMMENTS
XEQ COMP	K? ⋮ W MIN?	enter all data as prompted for, then:
1 [R/S]	W MAX?	
10,000 [R/S]	STEPS?	
10 [R/S]	dB MIN?	be sure to note the vertical scale multiplier when these data are entered
-77.2 [R/S]	dB MAX?	
60 [R/S]	∡ MIN?	
-260 [R/S]	∡ MAX?	
-95 [R/S]	Printed output on next page.	

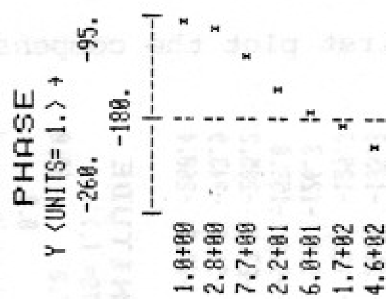
Now hold the overlayed plots up to a light and align the axes. It is clearly seen how the lag compensator shifted the gain crossover frequency to the left and caused the characteristic "hump" on the phase plot. It can also be seen that the ends of the response curves converge and the compensator becomes ineffective at these frequencies.

DATA

FREQ	dB	∠
1.000+00	60.0	-95.8
2.783+00	50.8	-105.7
7.743+00	40.2	-128.2
2.154+01	25.8	-156.3
5.995+01	8.8	-174.0
1.668+02	-9.0	-186.0
4.642+02	-27.5	-203.7
1.292+03	-48.7	-231.8
3.594+03	-73.7	-254.3
1.000+04	-100.0	-264.

2





Notice that the last point (10,000 rad/s) on the uncompensated response is experiencing compression caused by the fixed scales. This is of no concern, though, if it is realized that this point is unreliable.

USER INSTRUCTIONS

SIZE: (HP-41C) 018

STEP	INSTRUCTIONS	INPUT	FUNCTION	DISPLAY
1	Enter program			
2	Initialize		XEQ BODE	K=?
3	Input data as prompted	K	[R/S]	M=?
	(number of zeros)	M	[R/S]	Z?
	(real part)	Z	[R/S]	JZ?
	(imaginary part)	JZ	[R/S]	N=?
	(number of poles)	N	[R/S]	P?
	(real part)	P	[R/S]	JP?
	(imaginary part)	JP	[R/S] *	Y AUTOFREQ N
4	Determine auto/manual scaling	yes	A	STEPS?
		no	E	W MIN?
	(min frequency)	freq	[R/S]	W MAX?
	(max frequency)	freq	[R/S]	STEPS?
5	Number of points to plot	nn	[R/S]	Printed Output
	*NOTE: Go to 6, with no printer			
6	Single point computation		XEQ PT	W?
7	Frequency	freq	[R/S]	MAG=
			[R/S]	∡ =
8	Gain margin		XEQ GM	W1?
		freq	[R/S]	W2?
		freq	[R/S]	GM=
	(output ω_p)			FREQ=
9	Phase margin		XEQ PM	W1?
		freq	[R/S]	W2?

USER INSTRUCTIONS

SIZE: (HP-41C) 018

STEP	INSTRUCTIONS	INPUT	FUNCTION	DISPLAY
		freq	[R/S]	PM=
	(output ω_c)			FREQ=
10	Compare subroutine		XEQ COMP	same as 2 & 3 to the *
	then...			W MIN?
		freq	[R/S]	W MAX?
		freq	[R/S]	STEPS?
		nn	[R/S]	dB MIN?
		nn	[R/S]	dB MAX?
		nn	[R/S]	∡ MIN?
		nn	[R/S]	∡ MAX?
				Printed Output

011960

PROGRAM LISTING

☐ 67 ☐ 97 ☒ 41C

STEP/LINE	KEY ENTRY	KEY CODE (67/97 only)	COMMENTS
01	♦LBL "BODE"		initialize
02	CLRG		
03	SF 27		
04	115		
05	STO 02		
06	17.4		
07	STO 05		
08	"K=?"		read in the constant K
09	PROMPT		
10	STO 07		
11	"M=?"		enter number of zeros
12	PROMPT		
13	X=0?		
14	GTO 00		
15	STO 06		
16	♦LBL "N"		read in the zeros
17	"Z?"		
18	PROMPT		
19	ISG 05		
20	STO IND 05		
21	"JZ?"		
22	PROMPT		
23	ISG 05		
24	STO IND 05		
25	DSE 06		
26	GTO "N"		
27	♦LBL 00		store last zero in REG 08
28	RCL 05		
29	INT		
30	1000		
31	/		
32	STO 08		
33	"N=?"		enter number of poles
34	PROMPT		
35	X=0?		
36	GTO 00		
37	STO 06		
38	♦LBL "O"		read in poles
39	"P?"		
40	PROMPT		
41	ISG 05		
42	STO IND 05		
43	"JP?"		
44	PROMPT		
45	ISG 05		
46	STO IND 05		

STEP/LINE	KEY ENTRY	KEY CODE (67/97 only)	COMMENTS
47	DSE 06		
48	GTO "O"		
49	♦LBL 00		store last pole in REG 09
50	RCL 05		
51	INT		
52	1000		
53	/		
54	STO 09		
55	FC? 55		automatic frequency computations (scaling)
56	GTO "PT"		
57	FS? 02		
58	GTO E		
59	"Y AUTOFREQ N"		
60	PROMPT		
61	♦LBL A		
62	FC? 55		
63	GTO "PT"		
64	RCL 09		
65	18		
66	+		
67	STO 05		
68	1 E99		
69	STO 12		
70	♦LBL 06		
71	RCL IND 05		
72	ISG 05		
73	RCL IND 05		
74	X=0?		
75	GTO 00		
76	X↑2		
77	X<>Y		
78	X↑2		
79	+		
80	SQRT		
81	X<>Y		
82	♦LBL 00		
83	X<>Y		
84	X=0?		
85	GTO 00		
86	ABS		look for min & max break frequencies
87	RCL 10		
88	X<>Y		
89	X>Y?		
90	STO 10		
91	RCL 12		
92	X<>Y		
93	X<Y?		
94	STO 12		

Note: Refer to "HP-41C OWNER'S HANDBOOK AND PROGRAMMING GUIDE" for specific information on keystrokes. The Function Index is found at the very back of the Handbook. Refer to Appendix E in 67 or 97 "OWNER'S HANDBOOK AND PROGRAMMING GUIDE" for exact keystrokes.

01196C

PROGRAM LISTING

☐ 67 ☐ 97 ☒ 41C

STEP/LINE	KEY ENTRY	KEY CODE (67/97 only)	COMMENTS
95	♦LBL 00		
96	ISG 05		
97	GTO 06		
98	RCL 10		
99	10		compute one decade above & below the max & min break frequency
100	*		
101	LOG		
102	STO 10		
103	RCL 12		
104	10		
105	/		
106	LOG		
107	STO 12		
108	GTO 02		
109	♦LBL E		manual freq. scale read in
110	FC? 55		
111	GTO "PT"		
112	"W MIN?"		
113	PROMPT		
114	LOG		
115	STO 12		
116	"W MAX?"		
117	PROMPT		
118	LOG		
119	STO 10		
120	♦LBL 02		initialize the vertical scale registers & counters.
121	FS? 55		
122	SF 21		
123	FS? 02		
124	GTO 00		
125	-180		
126	STO 16		
127	STO 17		
128	0		
129	STO 00		
130	STO 01		
131	♦LBL 00		
132	RCL 12		
133	STO 13		
134	RCL 09		
135	1000		
136	*		
137	1		
138	+		
139	ENTER↑		
140	"STEPS?"		
141	PROMPT		
142	STO 11		
143	2		
144	*		

STEP/LINE	KEY ENTRY	KEY CODE (67/97 only)	COMMENTS
145	+		
146	1		
147	-		
148	ENTER↑		
149	ENTER↑		
150	1000		
151	/		
152	R↑		
153	+		
154	STO 06		
155	SF 25		check to see if there is enough memory available, output message if necessary
156	STO IND Y		
157	FS?C 25		
158	GTO 00		
159	FIX 0		
160	1		
161	ST+ Z		
162	"SET SIZE "		
163	ARCL Z		
164	PROMPT		
165	♦LBL 00		compute freq. increments
166	RCL 11		
167	1		
168	-		
169	RCL 10		
170	RCL 12		
171	-		
172	X<>Y		
173	/		
174	STO 11		
175	FC? 02		
176	GTO "K"		
177	"dB MIN?"		input scale data in COMP subroutine
178	PROMPT		
179	STO 00		
180	"dB MAX?"		
181	PROMPT		
182	STO 01		
183	"∡ MIN?"		
184	PROMPT		
185	STO 17		
186	"∡ MAX?"		
187	PROMPT		
188	STO 16		
189	♦LBL "K"		
190	CF 00		

01196C

PROGRAM LISTING

☐ 67 ☐ 97 ☒ 41C

STEP/ LINE	KEY ENTRY	KEY CODE (67/97 only)	COMMENTS
191	0		
192	STO 15		
193	1		
194	STO 14		
195	RCL 08		
196	17		
197	+		
198	STO 05		
199	♦LBL 03		
200	ISG 05		initialize the
201	GTO 00		computing
202	GTO 04		routine
203	♦LBL 00		
204	XEQ "L"		
205	GTO 03		determine if
206	♦LBL 04		term is from
207	1		the numerator
208	ST- 05		or denominator
209	SF 00		
210	RCL 09		
211	RCL 05		
212	INT		
213	+		
214	STO 05		
215	♦LBL 05		
216	ISG 05		
217	GTO 00		
218	GTO 07		
219	♦LBL 00		
220	XEQ "L"		
221	GTO 05		
222	♦LBL "L"		
223	RCL IND 05		
224	ISG 05		the calculation
225	RCL IND 05		is performed here
226	RCL 13		
227	10↑X		
228	+		
229	X<>Y		
230	R-P		
231	FS? 00		
232	GTO 01		
233	ST* 14		
234	X<>Y		
235	ST+ 15		
236	RTN		
237	♦LBL 01		
238	X≠0?		
239	GTO 00		
240	RDN		
241	1 E-99		
242	♦LBL 00		
243	ST/ 14		
244	X<>Y		
245	ST- 15		
246	RTN		
247	♦LBL 07		
248	RCL 14		
249	RCL 07		constant K
250	*		is multiplied
251	FC? 21		and the magni-
252	STO 14		tude is con-
253	X=0?		verted to dB
254	1 E-99		
255	LOG		
256	20		
257	*		
258	FC? 21		
259	RTN		
260	STO IND 06		
261	ISG 06		
262	FS? 02		
263	GTO 00		
264	RCL 00		
265	X<>Y		
266	X<Y?		
267	STO 00		
268	RCL 01		
269	X<>Y		
270	X>Y?		
271	STO 01		min & max
272	♦LBL 00		magnitude &
273	RCL 15		angle search
274	STO IND 06		
275	FS? 02		then store
276	GTO 00		data and
277	RCL 17		loop back to
278	X<>Y		calculate the
279	X<Y?		next freq.
280	STO 17		
281	RCL 16		
282	X<>Y		
283	X>Y?		
284	STO 16		
285	♦LBL 00		
286	RCL 11		

Note: Refer to "HP-41C OWNER'S HANDBOOK AND PROGRAMMING GUIDE" for specific information on keystrokes. The Function Index is found at the very back of the Handbook. Refer to Appendix E in 67 or 97 "OWNER'S HANDBOOK AND PROGRAMMING GUIDE" for exact keystrokes.

01196C

PROGRAM LISTING

☐ 67 ☐ 97 ☒ 41C

STEP/LINE · KEY ENTRY · KEY CODE (67/97 only) · COMMENTS

```
287 ST+ 13
288 ISG 06
289 GTO "K"
```

```
290 CF 02
291 ADV
292 SF 12
293 "DATA"
294 ACA
295 4
296 SKPCHR
297 ADV
298 CF 12
299 "FREQ"
300 ACA
301 6
302 SKPCHR
303 "dB"
304 ACA
305 5
306 SKPCHR
307 "∡"
308 ACA
309 3
310 SKPCHR
311 ADV
```

print heading for DATA block

```
312 RCL 12
313 STO 13
314 RCL 06
315 1
316 -
317 INT
318 1000
319 /
320 STO 14
321 1000
322 ST* 09
323 RDN
324 RCL 09
325 +
326 STO 05
327 ISG 05
328◆LBL "Q"
329 SCI 3
330 RCL 13
331 10↑X
332 ACX
333 2
334 SKPCHR
335 FIX 1
336 RCL IND
05
```

initialize counter & print data

```
337 ACX
338 2
339 SKPCHR
340 ISG 05
341 RCL IND
05
342 ACX
343 PRBUF
344 ISG 05
345 GTO 00
346 GTO 01
347◆LBL 00
348 RCL 11
349 ST+ 13
350 GTO "Q"
```

print data

```
351◆LBL 01
352 SF 12
353 ADV
354 "MAGNITU
DE"
355 ACA
356 1
357 SKPCHR
358 ADV
359 CF 12
360 0
361 STO 04
362 XROM "PR
AXIS"
363 SCI 1
364 RCL 09
365 1.00002
366 +
367 RCL 14
368 +
369 STO 05
370 RCL 12
371 STO 13
372 XEQ "M"
```

print heading for MAGNITUDE plot & branch to the plotting routine

```
373 SF 12
374 "PHASE"
375 ACA
376 3
377 SKPCHR
378 ADV
379 CF 12
380 -180
381 STO 04
382 RCL 17
383 STO 00
384 RCL 16
385 STO 01
```

print heading for PHASE plot and continue into the plotting routine

Note: Refer to "HP-41C OWNER'S HANDBOOK AND PROGRAMMING GUIDE" for specific information on keystrokes. The Function Index is found at the very back of the Handbook. Refer to Appendix E in 67 or 97 "OWNER'S HANDBOOK AND PROGRAMMING GUIDE" for exact keystrokes.

01196C

PROGRAM LISTING

☐ 67 ☐ 97 ☒ 41C

STEP/LINE	KEY ENTRY	KEY CODE (67/97 only)	COMMENTS
386	XROM "PR AXIS"		
387	RCL 09		
388	2.00002		
389	+		
390	RCL 14		
391	+		
392	STO 05		
393	SCI 1		
394	RCL 12		
395	STO 13		
396	1000		
397	ST/ 09		
398	♦LBL "M"		
399	RCL 13		
400	10↑X		
401	ACX		
402	4		
403	SKPCOL		plotting
404	RCL IND 05		routine
405	REGPLOT		
406	RCL 11		
407	ST+ 13		
408	ISG 05		
409	GTO "M"		
410	FIX 4		
411	ADV		
412	RTN		
413	♦LBL "PT"		
414	CF 21		
415	"W=?"		
416	PROMPT		
417	LOG		single point
418	STO 13		routine
419	XEQ "K"		
420	FIX 1		
421	"MAG="		
422	ARCL 14		
423	"⊢="		
424	ARCL X		
425	"⊢dB"		
426	AVIEW		
427	STOP		outputs data
428	"∡="		then loops
429	ARCL 15		back to repeat
430	AVIEW		for a new
431	FIX 4		frequency
432	STOP		
433	GTO "PT"		
434	♦LBL "GM"		

STEP/LINE	KEY ENTRY	KEY CODE (67/97 only)	COMMENTS
435	SF 01		
436	♦LBL "PM"		
437	CF 21		
438	"W1?"		
439	PROMPT		initialize the
440	LOG		gain &/or phase
441	STO 12		margin computa-
442	"W2?"		tions
443	PROMPT		
444	LOG		Flag 01 set for
445	STO 10		gain margin
446	STO 13		
447	XEQ "K"		
448	FS? 01		
449	RCL 15		
450	STO 00		
451	RCL 12		
452	STO 13		
453	XEQ "K"		linear inter-
454	FS? 01		polation
455	RCL 15		computation
456	STO 01		
457	FC? 01		
458	GTO 00		
459	180		
460	+		
461	♦LBL 00		compares to
462	RCL 12		1.0 for the
463	RCL 10		magnitude (PM)
464	-		or +180° for
465	*		angle (GM)
466	RCL 01		
467	RCL 00		
468	-		
469	/		
470	CHS		
471	RCL 12		
472	+		
473	STO 13		
474	XEQ "K"		
475	SF 21		
476	FS? 01		
477	GTO 00		
478	RCL 14		
479	1.005		
480	X<=Y?		
481	GTO 01		chexks the
482	RDN		accuracy of
483	.995		
484	X>Y?		PM
485	GTO 01		

01196C

PROGRAM LISTING

☐ 67 ☐ 97 ☒ 41C

STEP/ LINE	KEY ENTRY	KEY CODE (67/97 only)	COMMENTS
486	RCL 15		
487	180		
488	+		outputs the phase margin
489	FIX 1		
490	"PM="		
491	ARCL X		
492	AVIEW		
493	GTO F		
494	♦LBL 00		checks the accuracy of GM
495	CF 01		
496	RCL 15		
497	ABS		
498	180.005		
499	X<=Y?		
500	GTO 01		
501	RDN		
502	179.995		
503	X>Y?		
504	GTO 01		
505	RDN		
506	RDN		
507	FIX 1		outputs the gain margin
508	"GM="		
509	ARCL X		
510	"⊢dB"		
511	AVIEW		
512	♦LBL F		outputs freq. for GM, PM, or any single frequency operation
513	FIX 4		
514	RCL 13		
515	10↑X		
516	"FREQ="		
517	ARCL X		
518	AVIEW		
519	RTN		
520	♦LBL 01		GM/PM message
521	"BAD DATA"		
522	AVIEW		
523	RTN		
524	♦LBL "COMP"		sets flag 02 and branches to beginning of program
525	SF 02		
526	GTO "BODE"		
527	END		

STEP/ LINE	KEY ENTRY	KEY CODE (67/97 only)	COMMENTS
51			
60			
70			
80			
90			
00			

011960

REGISTERS, STATUS, FLAGS, ASSIGNMENTS

DATA REGISTERS

00	Y min	(see printer book)
01	Y max	
03	Plotting character	
04	Axis	
05	Counter	
06	Counter	
07	K	
08	Last zero	
09	Last pole	
10	ω max	
11	ω increment	
12	ω min	
13	ω counter	
14	Mag } accumulator	
15	∡ } accumulator	
16	∡ max	
17	∡ min	

* Varies with the number of points to be plotted.
** Automatically set and cleared in the program.

STATUS

SIZE 018 TOT. REG. * USER MODE ON ** OFF
ENG ** FIX SCI
DEG ** RAD GRAD

FLAGS

#	INIT S/C	SET INDICATES	CLEAR INDICATES
00	**	Denominator	Numerator
01	**	Compute PM	Compute GM
02	**	Compare	Normal
21	**	Printer on	No printer
55	**	...same as 21...	

ASSIGNMENTS

FUNCTION	KEY	FUNCTION	KEY
AUTOFREQ	A		
Manual freq	E		
FREQ=	F		