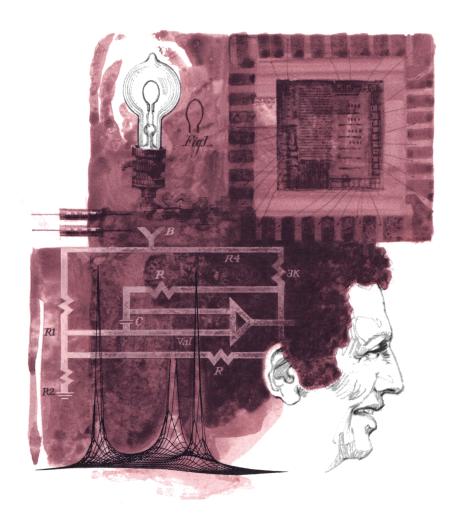
HP67 HP97

E.E. Pac I



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WE NEED YOUR HELP

To provide better calculator support for people like you, we need your help. Your timely inputs will enable us to provide high quality software in the future and improve the existing application pacs for your calculator. Your early reply will be extremely helpful in this effort.

1.	Pac name					
2.	How important was the availability of this pac in making your decision to buy a Hewlett-Packard calculator? ☐ Would not buy without it. ☐ Important ☐ Not important					
3.	Did you buy this pac and your calculator at the same time? ☐ Yes ☐ No					
	In deciding to buy this application pac, which three programs seemed most useful to you? Program numbers 1 2 3					
5.	Which three programs in this application pac seemed least useful to you? Program numbers 123					
6.	What program(s) would you add to this pac?					
7.	In the list below and "please" select up to three application areas for which you purchased this pac. Please indicate the order of importance by 1, 2, 3 (1 represents the most important area).					
	Engineering — 01 Chemical — 02 Civil/Structural — 03 Electrical/Electronic — 04 Industrial — 05 Mechanical — 06 Surveying — 10 Other (Specify) — 58 Marketing — 51 Accounting — 52 Banking — 53 Insurance — 54 Investment Analysis — 55 Real Estate — 56 Securities — 57 Sales — 58 Marketing					
	Science					
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ATTENTION: APPLICATIONS

INTRODUCTION

The 18 programs of EE Pac 1 have been drawn from the fields of network analysis, network synthesis, transistor theory, and microwave engineering.

Each program in this pac is represented by one or more magnetic cards and a section in this manual. The manual provides a description of the program with relevant equations, a set of instructions for using the program, and one or more example problems, each of which includes a list of the actual keystrokes required for its solution. Program listings for all the programs in the pac appear at the back of this manual. Explanatory comments have been incorporated in the listings to facilitate your understanding of the actual working of each program. Thorough study of a commented listing can help you to expand your programming repertoire since interesting techniques can often be found in this way.

On the face of each magnetic card are various mnemonic symbols which provide shorthand instructions to the use of the program. You should first familiarize yourself with a program by running it once or twice while following the complete User Instructions in the manual. Thereafter, the mnemonics on the cards themselves should provide the necessary instructions, including what variables are to be input, which user-definable keys are to be pressed, and what values will be output. A full explanation of the mnemonic symbols for magnetic cards may be found in appendix A.

If you have already worked through a few programs in Standard Pac, you will understand how to load a program and how to interpret the User Instructions form. If these procedures are not clear to you, take a few minutes to review the sections, Loading a Program and Format of User Instructions, in your Standard Pac.

We hope that EE Pac 1 will assist you in the solution of numerous problems in your discipline. We would very much appreciate knowing your reactions to the programs in this pac, and to this end we have provided a questionnaire inside the front cover of this manual. Would you please take a few minutes to give us your comments on these programs? It is in the comments we receive from you that we learn how best to increase the usefulness of programs like these.

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	This program computes various transfer functions of a ladder network composed of any number of standard elements.
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15.	Transmission Line Calculations

16.	Unilateral Design: Figure of Merit, Maximum Unilateral Gain,
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	This program computes u, G_u , G_{min} , G_{max} , G_0 , G_{1max} , and G_{2max} from a transistor's s-parameters. It also computes r_{0i} and ρ_{0i} from $G_i \leq G_{imax}$ $(i = 1, 2)$.
17.	Bilateral Design: Stability Factor, Maximum Gain,
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	This program computes the maximum gain available and the load and source reflection coefficients which yield the maximum gain.
18.	Bilateral Design: Gain and Stability Circles, Load and
	Source Mapping
	This program computes the location and radius of stability circles.
	It also computes the source or load reflection coefficient
	corresponding to a given load or source termination.
	ram Listing Contents

A WORD ABOUT PROGRAM USAGE

This application pac has been designed for both the HP-97 Programmable Printing Calculator and the HP-67 Programmable Pocket Calculator. The most significant difference between the HP-67 and the HP-97 calculators is the printing capability of the HP-97. The two calculators also differ in a few minor ways. The purpose of this section is to discuss the ways that the programs in this pac are affected by the differences in the two machines, and to suggest how you can make optimal use of your machine, be it an HP-67 or an HP-97.

Most of the computed results in this pac are output by PRINT statements: most often by the statement PRINTx, and occasionally by the command PRINT STACK. On the HP-97, these results will be output on the printer. On the HP-67, each PRINT command will be interpreted as a PAUSE: the program will halt, display the result for up to two seconds, then continue execution. The term "PRINT/PAUSE" is used to describe this output condition.

If you own an HP-67, you may want more time to copy down the number displayed by a PRINT/PAUSE. All you need to do is press down any key on the keyboard. If the command being executed is PRINTx (eight rapid blinks of the decimal point), pressing down a key will cause the program to halt. If the command being executed is PRINT STACK (two slow blinks of the decimal point for each value), the number in the display will remain there until the depressed key is released; then the next register in the stack will be displayed, and so on. After display of all four registers, the program will halt execution if a key was pressed at any time during the display of the stack contents. In both cases, execution of the halted program may be re-initiated by pressing R/S.

For output purposes, a "display" subroutine has been incorporated into most of the programs in this pac. This routine makes important use of internal flag 0 as follows:

```
Flag 0 "Set" — PRINT/PAUSE is enabled for output of result.

Flag 0 "Clear" — PRINT/PAUSE is skipped and program execution halts with result in display.
```

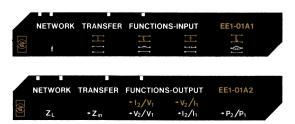
Every program with this feature has flag 0 "set", initially. Thus, the user who is content to have his data output by PRINT/PAUSE simply loads the program and begins execution. The user who desires that the machine stop to display each result must press CLF 0 (CLEAR FLAG 0) after loading the program.

The HP-97 users may also want to keep a permanent record of the values input to a certain program. A convenient way to do this is to set the Print Mode switch to NORMAL before running the program. In this mode, all input values and their corresponding user-definable keys will be listed on the printer, thus providing a record of the entire operation of the program.

Another area that could reflect differences between the HP-67 and the HP-97 is in the keystroke solutions to example problems. It is sometimes necessary in these solutions to include operations that involve prefix keys, namely, on the HP-97 and 1, 9, and 1 on the HP-67. For example, the operation $\overline{\mathbf{10}^{\times}}$ is performed on the HP-97 as $\overline{\mathbf{10}^{\times}}$ and on the HP-67 as $\overline{\mathbf{10}^{\times}}$. In such cases, the keystroke solution omits the prefix key and indicates only the operation (as here, $\overline{\mathbf{10}^{\times}}$). As you work through the example problems, take care to press the appropriate prefix keys (if any) for your calculator.

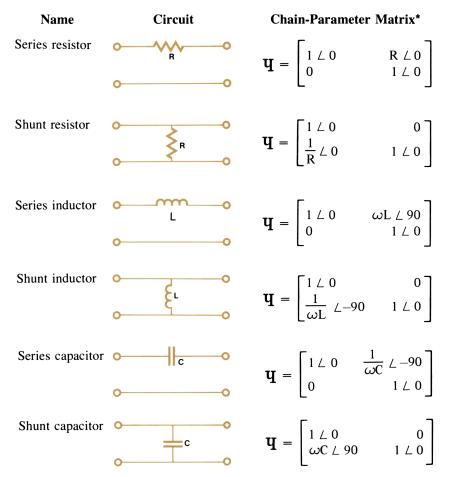
Also in keystroke solutions, those values which are output by the command PRINTx will be followed by three asterisks (***).

NETWORK TRANSFER FUNCTIONS

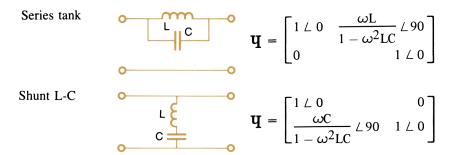


This program computes various transfer functions of a ladder network composed of any number of standard elements. The ladder is built up one element at a time by selecting shunt or series elements from the following menu.

MENU OF CIRCUIT ELEMENTS



^{*} Ч is the Cyrillic letter "cha".



The chain-parameter matrix is defined by the following sketch and matrix equation.

$$\begin{bmatrix} \mathbf{I}_1 & & & & \\ & \mathbf{V}_1 & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ &$$

The operation of the program is based on the fact that the chain-parameter matrix of two cascaded circuits is equal to the product of their individual chain-parameter matrices.

As the circuit is built up from right to left, the overall chain-parameter matrix is updated with the addition of each element. When the circuit description is complete, the second card is read in and any of the following transfer functions may be computed from the overall chain-parameter matrix.

Input impedance

$$Z_{in} = \frac{ \mathbf{q}_{11} \, Z_L + \mathbf{q}_{12} }{ \mathbf{q}_{21} \, Z_L + \mathbf{q}_{22} }$$

Voltage transfer ratio

$$\frac{V_2}{V_1} = \frac{Z_L}{\Psi_{11} Z_L + \Psi_{12}}$$

Current transfer ratio

$$\frac{I_2}{I_1} = \frac{-1}{\Psi_{21} Z_L + \Psi_{22}}$$

Power Gain

$$\frac{P_{\text{out}}}{P_{\text{in}}} = \left| \frac{I_2}{I_1} \right|^2 \frac{\text{Re } \{Z_L\}}{\text{Re } \{Z_{\text{in}}\}} Z_L$$

Forward transfer admittance

$$\frac{I_2}{V_1} = \frac{-1}{\Psi_{11} Z_L + \Psi_{12}}$$

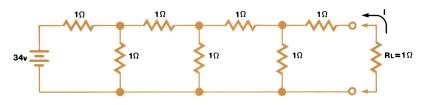
Forward transfer impedance

$$\frac{V_2}{I_1} = \frac{Z_L}{\Psi_{21} Z_L + \Psi_{22}}$$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load program 1.			
2	Input frequency and initialize.	f, Hz	A	0
3	Build circuit by selecting			
	any sequence of the			
	following elements.			
	Series resistor	R	В	
	Series inductor	L	0	
	Series capacitor	С	D	
	Series tank	L	ENTER+	
		С	E	
	Shunt resistor	R	■ B	
	Shunt inductor	L	o C	
	Shunt capacitor	С		:
	Shunt L-C	L	ENTER+	
		С		
4	Load program 2.			
5	Input load impedance.	۷ . کا	ENTER+	
		Z _L	A	
6	Select desired network			
	function:			
	Input impedance		В	$\angle Z_{in}$
				$ Z_{in} $
	voltage gain		G	LV_2/V_1
				$ V_2/V_1 $
	current gain		0	\perp I_2/I_1
				I ₂ /I ₁
	Transfer admittance		I C	∠ I ₂ /V ₁
				I ₂ /V ₁
	Transfer impedance			∠ V ₂ /I ₁
				V ₂ /I ₁
	Power gain		3	P ₂ /P ₁

Example 1:

What current will flow in a 1Ω resistor placed on the output of this network? What is the input impedance?



Keystrokes:

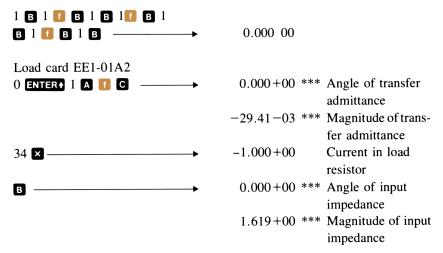
Outputs:

Load card EE1-01A1



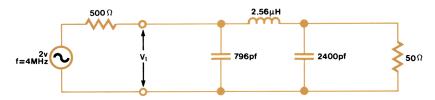
Note:

No frequency need be input for a purely resistive network, but initialization is still necessary.



Example 2:

This program can be used to compute voltages within a network by dividing the problem into two parts. Find the voltage V_1 in the circuit shown.



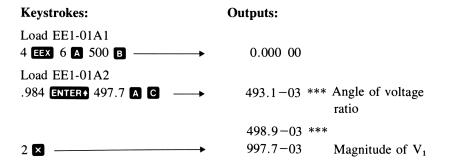
01-05

Solution:

First compute the input impedance of the circuit to the right of V₁.

Keystrokes:	Outputs:
Load EE1-01A1	
4 EEX 6 A 2400 EEX CHS	
12 1 D 2.56 EEX CHS 6 C	
796 EEX CHS $12 \ \blacksquare$ D \longrightarrow	0.000 00
Load EE1-01A2	
0 ENTER+ 50 A B →	984.0-03 *** Angle of input
	impedance
	497.7 00 *** Magnitude of input
	impedance

Then compute the voltage transfer ratio for the network to the left of V_1 terminated in 497.7 \angle 0.984.



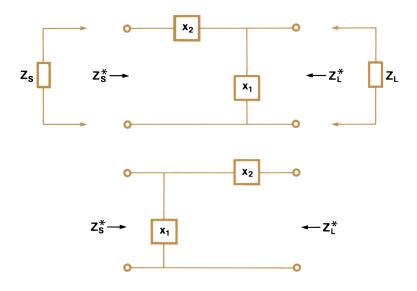
Notes

2. REACTIVE L-NETWORK IMPEDANCE MATCHING



An L-network consisting of purely reactive elements may be used to transform any complex impedance into any other complex impedance. In general, there are four possible networks, but in some situations there are only two. This program accepts complex load and source impedances in rectangular form and outputs all possible solutions, displaying an error message if a given topology is not suitable.

Either of these two networks is possible:



For each network there are two sets of reactances (X_1, X_2) that will transform Z_L into Z_S^* . These are given by:

$$X_{1} = \frac{R_{S} X_{L}}{R_{S} - R_{L}} \pm \sqrt{\left(\frac{R_{S} X_{L}}{R_{S} - R_{L}}\right)^{2} - \frac{R_{S} (X_{L}^{2} + R_{L}^{2})}{R_{S} - R_{L}}}$$

$$X_{2} = \frac{R_{S} (X_{1} + X_{L}) - R_{L} (X_{1} + X_{S})}{R_{L}}$$

By reversing the subscripts S and L in these two equations, we get the two sets of reactances for the second network.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load program.			
2	Input			
	Load impedance			
	Reactive part	X _L , Ω	ENTER+	X _L , Ω
	Resistive part	R_{L},Ω	A	X_L , Ω
	Source impedance			
	Reactive part	X _s , Ω	ENTER+	X _s , Ω
	Resistive part	R _s , Ω	B	X_s , Ω
3	Compute values for first			
	network.			
	Shunt reactance		0	X ₁ , Ω
	Series reactance			X_2 , Ω
	Shunt reactance		(Χ 1, Ω
	Series reactance			X_2 , Ω
4	Compute values for second			
	network.			
	Shunt reactance		0	X ₁ , Ω
	Series reactance			X ₂ , Ω
	Shunt reactance			X ₁ , Ω
	Series reactance			Χ ₂ , Ω
	Note: If one of the above			
	networks is inappropriate,			
	an error message will occur.			
	Simply press any key and			
	continue with the next type			
	of network.			

02-03

Example:

What reactive L-networks could be used to match $Z_L = 50 + j50$ to $Z_S = 25 + j50$?

Keystrokes:

Outputs:

25 **B f C**
$$\longrightarrow$$
 -36.60 *** X_1 -6.70 *** X_2

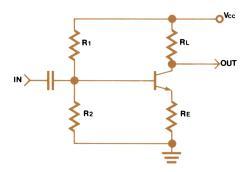
$$\begin{array}{c} -38.76 *** X_1 \\ 11.24 *** X_2 \end{array}$$

Notes

3. CLASS A TRANSISTOR AMPLIFIER BIAS OPTIMIZATION



This program is an automation of the method of bias optimization described in "Designing class A amplifiers to meet specified tolerances" by Ward J. Helms (Electronics/August 8, 1974). The program requires the user to specify a number of items from which it determines by an iterative technique the optimum values for R_1 , R_2 , R_E , and R_L . The minimum power gain is also computed.



Equations:

First, values are specified for the following parameters:

 ΔI_{CQ} = maximum desired percentage variation of quiescent current

 T_{Amax} = maximum ambient temperature (use the maximum case temperature for a transistor mounted on a heat sink)

 T_{Amin} = minimum ambient temperature

 T_{Jmax} = maximum junction temperature rating

 P_D = maximum rated power dissipation at 25°C

 I_1 = collector current, usually selected for convenience so that I_1 and 10 I_1 bracket the expected operating point

 ΔV_{BE} = typical base-emitter voltage change over the range of I_1 to $10\ I_1$ at $25^{\circ}C$

 V_{BE1min} = minimum base-emitter voltage at I_1 , 25°C

 V_{BE1max} = maximum base-emitter voltage at I_1 , 25°C

Then the transistor's thermal resistance is calculated:

$$\theta_{\rm JA} = (T_{\rm max} - 25^{\circ} \rm C)/P_{\rm D}$$

And the minimum load resistance and emitter resistance are estimated:

$$R_{L1} = \frac{\theta_{JA} \ V_{CC}^2}{4.4 \ (T_{Jmax} - T_{Amax})} = R_{Ln}$$

$$R_{E1} = 0.1 R_{L1} = R_{En}$$

Next, the quiescent, maximum, and minimum collector currents are calculated:

$$I_{CQ} = \frac{V_{CC}}{2 (R_{Ln} + R_{En})}$$

$$I_{Cmax} = I_{CQ} (1 + \Delta I_{CQ})$$

$$I_{Cmin} = I_{CQ} (1 - \Delta I_{CQ})$$

From these, we can calculate the base-emitter voltage under hot, high-current conditions (V_{BEX}) and under cold, low-current conditions (V_{BEX}).

$$\begin{split} T_{max} &= \theta_{JA} \ I_{CQ} \frac{V_{CC}}{2} + T_{Amax} \\ V_{BEX} &= V_{BE1min} + \Delta V_{BE} \log \frac{I_{Cmax}}{I_{1}} - 0.0022 (T_{max} - 25^{\circ}\text{C}) \\ T_{min} &= \theta_{JA} \ I_{CQ} \frac{V_{CC}}{2} \ (1 - (\Delta I_{CQ})^{2}) + T_{Amin} \end{split}$$

$$V_{BEN} = V_{BE1max} + \Delta V_{BE} log \frac{I_{Cmin}}{I_{.}} -0.0022 (T_{min} - 25^{\circ}C)$$

Now, a better estimate for the emitter resistance can be made:

$$R_{E(n+1)} = \frac{-\ 2\ (V_{BEX} - V_{BEN})}{I_{Cmax} - I_{Cmin}}$$

From this point, if $V_{BEX} > V_{BEN}$, then R_E is set to zero, R_L is increased by 10%, and the design procedure is repeated. Iterations continue until $\frac{R_{E(n+1)} - R_{En}}{R_{En}} < .5\%.$ If at any time the condition $T_{max} > T_{Jmax}$ occurs, R_L is increased by 10%.

When the iterative procedure is complete, T_{max} , I_{Cmax} , T_{min} , and I_{Cmin} are displayed.

Then values for

 $h_{FEmax} = maximum$ worst-case current gain at T_{max} or T_{min} and I_{Cmax} or I_{Cmin}

and

 h_{FEmin} = minimum worst-case current gain at T_{max} or T_{min} and I_{Cmax} or I_{Cmin}

are determined from the transistor's data sheet and the Thevenin-equivalent resistance (R_B) and voltage (V_{BB}) of the amplifier's bias network are calculated:

$$\begin{split} R_B \, = \, \frac{h_{FEmax} \, h_{FEmin} \, \left[R_{E(n+1)} \, (I_{Cmax} \, - \, I_{Cmin}) \, + \, V_{BEX} \, - \, V_{BEN} \right]}{h_{FEmax} \, I_{Cmin} \, - \, h_{FEmin} \, I_{Cmax}} \\ V_{BB} \, = \, \, V_{BEN} \, + \, I_{Cmin} \left(\frac{R_B}{h_{FEmin}} \, + R_{E(n+1)} \right) \end{split}$$

Now the bias resistors R_1 and R_2 are calculated:

$$R_1 = \frac{R_B V_{CC}}{V_{DD}}$$

$$R_2 = \frac{R_B V_{CC}}{(V_{CC} - V_{BB})}$$

Finally, the minimum power gain and minimum signal power are calculated:

$$A_{\rm P} \, = \, \frac{R_{\rm B} \, R_{\rm L} \, h_{\rm FEmin}}{R_{\rm E} \, (R_{\rm B} \, + \, h_{\rm FEmin} \, R_{\rm E})} \label{eq:AP}$$

$$P_{\rm S} = (1 - \Delta I_{\rm CQ})^2 \left(\frac{V_{\rm CC}^2 R_{\rm L}}{8 (R_{\rm L} + R_{\rm E})^2} \right)$$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
- 1	Load program.			
2	Store design objectives.			
	Power supply voltage	V _{cc}	STO 0	
	Maximum desired percent			
	variation of quiescent current	ΔΙ _{ςα}	STO 1	
	Maximum ambient			
	temperature	T _{Amax} , °C	STO 2	
	Minimum ambient			
	temperature	T _{Amin} , °C	STO 3	
3	Store values from transistor's			
	data sheet			
		T_{Jmax}	STO 4	
		P₀	STO 5	
		I ₁	STO 6	
		ΔV_{BE}	STO 7	
		$V_{\sf BE1min}$	STO 8	
		$V_{\sf BE1max}$	STO 9	
4	Compute maximum and	,		
	minimum temperatures and			
	currents; then stop with			
	500.0 -03 in display.		Δ	T_{max}
				I_{Cmax}
				T_{min}
				I_{Cmin}
5	Input maximum h _{FE}			
	and minimum h _{FE} and compute	h _{FEmax}	ENTER	
	resistor R₁	h _{FEmin}	R/S	R ₁
	resistor R₂			R₂
	load resistance			R_L
	emitter resistance			R₅
	minimum power gain			$A_{\mathtt{p}}$

Example:

A single-stage class A amplifier is needed to operate from a 30-V power supply. The maximum power output and maximum power gain must be obtained from a Texas Instruments type TIS98 transistor over an ambient temperature range of 0° C to 70° C, with a maximum quiescent-current variation of $\pm 20\%$.

From the transistor's data sheet, determine:

```
\begin{array}{lll} T_{Jmax} & = 150 ^{\circ} C \\ P_{D} & = 0.36 \ W \\ \Delta V_{BE} & = 0.10 \ v \ from \ 3 \ to \ 30 \ mA \\ V_{BE1min} & = 0.52 \ v \ at \ 3 \ mA \ at \ 25 ^{\circ} C \\ V_{BE1max} & = 0.72 \ v \ at \ 3 \ mA \ at \ 25 ^{\circ} C \\ I_{1} & = 0.001 \ A \end{array}
```

Keystrokes:

Outputs:

First store the data

- 30. **STO** 0
- .2 **STO** 1
- 70. **STO** 2
- 0. **STO** 3
- 150. **STO** 4
- .36 **STO** 5
- .001 **STO** 6
- .1 **STO** 7
- .52 **STO** 8
- .72 **STO** 9

Then compute maximum and minimum temperatures and currents

From the transistor's data sheet determine:

$$h_{FEmax} = 600 \text{ at } 150^{\circ}\text{C} \text{ at } 18 \text{ mA}$$

 $h_{FEmin} = 100 \text{ at } 80^{\circ}\text{C} \text{ at } 12 \text{ mA}$

Finish problem

Keystrokes:

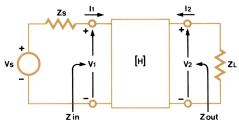
Outputs:

 $\begin{array}{ccccc} 45.0 + 03 & T & R_1 \\ 4.18 + 03 & Z & R_2 \\ 888. + 00 & Y & R_L \\ 115. + 00 & X & R_E \\ 22.9 + 00 & *** & A_P \end{array}$

4. TRANSISTOR AMPLIFIER PERFORMANCE



This program computes certain small-signal properties of a transistor amplifier given the h-parameter matrix and the source and load impedances. Properties computed are current and voltage gains and input and output impedances.



Equations:

Definition of h-parameter matrix

$$\begin{bmatrix} v_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} h_i & h_r \\ h_f & h_o \end{bmatrix} \begin{bmatrix} i_1 \\ v_2 \end{bmatrix}$$

Current gain

$$A_i \, = \, \frac{i_2}{i_1} \, = \, \frac{-h_f}{1 \, + \, h_o \, \, Z_L}$$

Voltage gain

$$A_{v} = \frac{v_2}{v_1} = \frac{A_i Z_L}{Z_{in}}$$

Voltage gain with source resistor

$$A_{vs} = \frac{v_2}{v_s} = \frac{A_i Z_L}{Z_{in} + Z_s}$$

Input impedance

$$Z_{in} = h_i + h_r Z_L A_i$$

Output impedance

$$Z_{out} = \frac{h_i + Z_S}{h_o h_i + h_o Z_S - h_f h_r}$$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load program.			
2	Input h-parameters.			
	Angle	$ heta_{\scriptscriptstyle ij}$, deg	ENTER+	
	Magnitude	h _{ij}	ENTER+	
	Designation	ij	A	
3	Input termination impedances.			
	Angle of source impedance	$ heta_{s}$, deg	ENTER+	
	Magnitude of source			
	impedance	Rs		
	Angle of load impedance	$ heta_{ t L}$, deg	ENTER+	
	Magnitude of load			
	impedance	RL	B	
4	Compute			
	Voltage gain		C	A_{v}
	Current gain		[] G	A _i
	Voltage gain with source			
	resistor		D	A _{vs}
	Input impedance		o e	Z _{in}
	Output impedance		8	Z_{out}

Example:

What are the small-signal properties of a transistor which has the following h-parameter matrix and has source and load impedances of 1000 and 10,000 ohms, respectively?

$$[h] = \begin{bmatrix} 1100 & 250E-6 \\ 50 & 25E-6 \end{bmatrix}$$

8

Keystrokes:	Outputs:
0 ENTER♦ 1100 ENTER♦ 11 A	
0 ENTER 250 EEX 6 CHS ENTER 12 A	
0 ENTER♦ 50 ENTER♦ 21 A	
0 ENTER 25 EEX CHS 6 ENTER ◆	
22 A	
0 ENTER 1000	0.000+00 *** \(\alpha \)
	$-400.0+00 *** A_v $
f C	$0.000+00 *** \angle A_{i}$
	$-40.00+00 *** A_i $
□	0.000+00 *** ∠A _{vs}
	$-200.0+00 *** A_{vs} $
1 E ──	0.000+00 *** ∠Z _{in}
	$1.000+03*** Z_{in} $

 $0.000 + 00 ~***~ \angle~Z_{out}$

52.50+03 *** |Z_{out}|

Notes

5. TRANSISTOR CONFIGURATION CONVERSION



This program converts among h-parameter matrices for common-base, common-emitter, and common-collector transistor configurations.

The program first converts the h-parameter matrix to a y-parameter matrix using the following transformation:

$$[y] = \frac{1}{h_{11}} \begin{bmatrix} 1 & -h_{12} \\ \\ \\ h_{21} & h_{11} h_{22} - h_{12} h_{21} \end{bmatrix}$$

The y-matrix is then transformed into a y'-matrix depending on the conversion desired:

CB
$$\rightarrow$$
 CE or CE \rightarrow CB
 $y'_{11} = y_{11} + y_{12} + y_{21} + y_{22}$
 $y'_{12} = -(y_{12} + y_{22})$
 $y'_{21} = -(y_{21} + y_{22})$
 $y'_{21} = -(y_{21} + y_{22})$
 $y'_{22} = y_{11}$
CC \rightarrow CB
 $y'_{11} = y_{22}$
 $y'_{12} = -(y_{21} + y_{22})$
 $y'_{21} = -(y_{12} + y_{22})$
 $y'_{22} = y_{11} + y_{12} + y_{21} + y_{22}$

$$CC \rightarrow CE \text{ or } CE \rightarrow CC$$

$$y'_{11} = y_{11}$$

$$y'_{12} = -(y_{11} + y_{12})$$

$$y'_{21} = -(y_{11} + y_{21})$$

$$y'_{21} = -(y_{11} + y_{21})$$

$$y'_{22} = y_{11} + y_{12} + y_{21} + y_{22}$$

$$CB \rightarrow CC$$

$$y'_{11} = y_{11} + y_{12} + y_{21} + y_{22}$$

$$y'_{12} = -(y_{11} + y_{21})$$

$$y'_{21} = -(y_{11} + y_{12})$$

$$y'_{22} = y_{11}$$

Finally the desired h-parameter matrix is derived from the y'-matrix by the [h] - [y] transformation used above.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load program.			
2	Input h-parameter matrix			
	(ij = 11, 12, 21, 22).			
	Angle of h-parameter	$ heta_{ij}$, deg	ENTER+	
	then Magnitude of			
	h-parameter	h _{ij}	ENTER+	
	then Designation of			
	h-parameter	ij	A	
3	Perform desired conversion.			
	CE→CB		B	
	CB→CE		■ B	
	CC→CB		G	
	CB→CC			
	CC→CE		0	
	CE→CC			
4	Display converted			
	h-parameter matrix.*		Œ	$ heta_{11}$
				h ₁₁
				$ heta_{12}$
				h ₁₂
				$ heta_{21}$
				h ₂₁
				$ heta_{22}$
				h ₂₂
	*This feature may be used at			
	any time to display whatever			
	matrix is in storage.			

Example:

Convert the following common-collector h-parameter matrix to common base.

$$\begin{bmatrix} h_{cc} \end{bmatrix} \; = \; \begin{bmatrix} h_{ic} & h_{rc} \\ h_{fc} & h_{oc} \end{bmatrix} \; = \; \begin{bmatrix} 1000 \; \angle \, 30 & 100 \times 10^{-6} \; \angle \, -45 \\ 60 \; \angle \, 30 & 30 \; \times \, 10^{-6} \; \angle \, 0 \end{bmatrix}$$

Keystrokes:

30 ENTER ↑ 1000 ENTER ↑ 11 A
45 CHS ENTER ↑ 100 EEX CHS
6 ENTER ↑ 12 A 30 ENTER ↑ 60
ENTER ↑ 21 A 0 ENTER ↑ 30 EEX
CHS 6 ENTER ↑ 22 A C E →

Outputs:

Notes

6. PARAMETER CONVERSION

Two-port S-parameters may be converted to and from any of Y, Z, G or H parameters using a single matrix equation. Appropriate pre- and postconditioning operations must be performed depending on which conversion is desired.

First, the preconditioning operation generates a T matrix. Then occurs the basic transformation

$$T' = (I + T)^{-1} (I - T)$$

$$= \frac{2}{(1 + t_{11}) (1 + t_{22}) - t_{12} t_{21}} \begin{bmatrix} 1 + t_{22} & -t_{12} \\ -t_{21} & 1 + t_{11} \end{bmatrix} - \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

Finally, the postconditioning operation is performed.

The preconditioning operations performed when converting from S are

$S \rightarrow Y$	$S \rightarrow Z$	S -	→ G	$S \to H$	
T = S	T = -S	$T = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$	$\begin{bmatrix} 0 \\ -1 \end{bmatrix}$ S	$T = \begin{bmatrix} -1 \\ 0 \end{bmatrix}$	$\begin{bmatrix} 0 \\ 1 \end{bmatrix}$ S

and those performed when converting to S are

$Y \rightarrow S$	$Z \rightarrow S$	$G \rightarrow S$		$H \rightarrow S$	
$T = Z_0 Y$	$T = Z/Z_0$	$T = \begin{bmatrix} Z_0 & g_{11} \\ g_{21} \end{bmatrix}$	g_{12}	$T = \begin{bmatrix} h_{11}/Z_0 \\ \end{bmatrix}$	h_{12}
0 _	, -0	g ₂₁	g_{22}/Z_0	_ h ₂₁	$h_{22} Z_0 $

The postconditioning operations performed when converting from S are

$S \to Y$	$S \rightarrow Z$	$S \rightarrow G$		$S \rightarrow H$	
$Y = T'/Z_0$	$Z = Z_0 T'$	$G = \begin{bmatrix} t_{11}'/Z_0 \\ t_{21}' \end{bmatrix}$	t_{12}'	$\mathbf{H} = \begin{bmatrix} \mathbf{t_{11}}' \ \mathbf{Z_0} \end{bmatrix}$	t_{12}'
/ -0	0 -	_ t ₂₁ '	$t_{22}'Z_0$	$\lfloor {t_2}_1'$	t_{22}'/Z_0

and those performed when converting to S are

$Y \rightarrow S$	$Z \rightarrow S$	$G \rightarrow S$		$H \rightarrow S$		
S = T'	S = -T'	$S = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$	0 -1 T'	S =	-1 0	0 1 T'

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load program.			
2	Input S, Y, Z, G, or H.			
	Angle of element ij	$ heta_{ij}$	ENTER+	
	Magnitude of element ij	M_{ij}	ENTER+	
	Subscript to element	ij	1 A	
3	Select desired conversion.			
	S→Y	Z _o	В	
	Y→S	Z _o	1 B	
	S→Z	Z _o	C	
	Z→S	Z_0		
	S→G	Z ₀	D	
	G→S	Z _o		
	S→H	Z _o	3	
	H→S	Z _o		
4	Display elements of new matrix.			
	Input element subscript	ij	A	
	Display angle of element ij			$ heta_{ij}$
	Display magnitude of			
	element ij			M_{ij}

Example:

The s-parameter matrix of a 2N3571 transistor is

$$S = \begin{bmatrix} 0.62 \ \angle -44.0 & 0.0115 \ \angle 75.0 \\ 9.0 \ \angle 130 & 0.955 \ \angle -6.0 \end{bmatrix}$$

What is the h-parameter matrix? Z_0 is 50 Ω .

Keystrokes: Outputs:

22 **[]** A 50 **E** 11 A
$$\longrightarrow$$
 -53.88 *** θ_{11} 119.1 *** h_{11}

12 A
$$\longrightarrow$$
 39.26 *** θ_{12} 18.14-03 *** h_{12}

21
$$\blacksquare$$
 94.26 *** θ_{21} -14.19 *** h_{21}

22 A
$$\longrightarrow$$
 21.17 *** θ_{22} 2.272-03 *** h_{22}

Notes

7. FOURIER SERIES



Any periodic function may be written as a series of sine and cosine waves by the application of the following formulas.

$$\begin{split} f(t) &= \frac{a_0}{2} + \sum_{i=1}^{\infty} \left(\begin{array}{cc} a_i \cos \frac{i2\pi t}{T} + b_i \sin \frac{i2\pi t}{T} \end{array} \right) \\ &= \frac{a_0}{2} + \sum_{i=1}^{\infty} c_i \sin \left(\frac{i2\pi t}{T} + \theta_i \right) \\ \\ a_i &= \frac{2}{T} \int_0^T f(t) \cos \frac{i2\pi t}{T} dt, \quad i = 0, 1, 2, \dots \\ \\ b_i &= \frac{2}{T} \int_0^T f(t) \sin \frac{i2\pi t}{T} dt, \quad i = 1, 2, \dots \\ \\ c_i &= (a_i^2 + b_i^2)^{\frac{1}{2}} \\ \\ \theta_i &= \tan^{-1} \left(\frac{a_i}{b_i} \right) \\ \\ T &= \text{period of } f(t) \end{split}$$

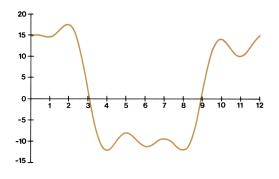
This program computes the Fourier coefficients from discrete versions of the above formulas given a large enough number of samples of the periodic function. Up to ten consecutive pairs of coefficients may be computed at one time from N equally spaced points. The coefficients may be displayed in either rectangular or polar form.

The value of N should be chosen to be more than twice the highest expected multiple of the fundamental frequency present in the wave to be analyzed. A low estimate for N will cause energy above one-half the sampling rate to appear at a lower frequency (a phenomenon known as aliasing).

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load program.			
2	Initialize		[] A	
3	Input			
	Number of samples			
	in one period	N	ENTER+	
	Number of frequencies			
	desired	#freqs	A	N
	Order of first coefficient	J	В	J
4	Input $y_k, k = 1, N$	Уĸ	G	2,, .111
5	Repeat step 4 until display			
	shows 0.111			
6	Display coefficients for			
	J≤i≤J+ #freqs			
	in polar form			i
				$ heta_{ ext{i}}$
				Ci
	in rectangular form.		D	i
				b _i
				a _i
7	Compute value of Fourier			
	series at t.	t	3	f(t)

Example:

Compute a discrete Fourier series representation for the waveform shown. Since there are 12 samples, select 7 frequencies (dc term plus 6 harmonics).



t	f(t
1	14.758
2	17.732
3	2
4	-12.
5	-7.758
6	-11
7	-9.026
8	-12.
9	2
10	14.268
11	10.026
12	15

Keystrokes:	Outputs:
\blacksquare A 12 ENTER 7 A 0 B \longrightarrow	1.000
14.758 C →	2.000
17.732 C —	3.000
2 ℃———	4.000
12 CHS C	5.000
7.758 CHS C — →	6.000
11 CHS C	7.000
9.026 CHS C	8.000
12 CHS C	9.000
2 C	10.000
14.268 C ————	11.000
10.026 C —	12.000

0.111
0. *** i
0.000 *** b_i
4.000 ***
1. ***
1.000 ***
15.000 ***

2. ***
1.000 ***
3.00000001-08 ***

3. ***
1.000 ***
-5.000 ***

4. ***
3.20000001-09 ***
3.33333334-09 ***

1.467291667-05 ***
3.000 ***

1.467291667-05 ***
3.000 ***

Thus
$$f(t) = 2 + 15 \cos \frac{2\pi t}{12} + \sin \frac{2\pi t}{12}$$

$$+ \sin \frac{4\pi t}{12}$$

$$- 5 \cos \frac{6\pi t}{12} + \sin \frac{6\pi t}{12}$$

 $+ 3 \cos \frac{10\pi t}{12}$

8. ACTIVE FILTER DESIGN



This program computes element values for the standard active filter circuits shown. The user selects corner frequency f_0 or center frequency f_0 , midband gain A, peaking factor α , and a capacitor C. The program then prints out a list of elements which form the desired filter.

Equations:

$$\alpha = \frac{1}{Q} = 2\zeta$$
, where Q is quality factor and ζ is damping factor.

Low pass filter

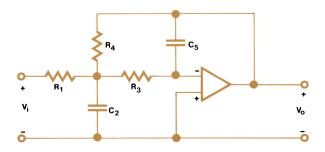
$$C_5 = C$$

$$C_2 = \frac{4C(A+1)}{\alpha^2}$$

$$R_1 = \frac{\alpha}{4A\pi f_0 C}$$

$$R_3 = \frac{\alpha}{4\pi f_0 C(A+1)} = \frac{A}{A+1} R_1$$

$$R_4 = AR_1$$



High pass filter

$$C_{1} = C_{3} = C$$

$$C_{4} = \frac{C}{A}$$

$$R_{2} = \frac{\alpha}{2\pi f_{0}C\left(2 + \frac{1}{A}\right)}$$

$$R_{5} = \frac{2A + 1}{\alpha 2\pi f_{0}C}$$

$$C_{4}$$

$$R_{5} = \frac{C}{\alpha}$$

$$C_{4}$$

$$C_{5}$$

$$C_{6}$$

$$C_{7}$$

$$C_{8}$$

$$C_{1}$$

$$C_{8}$$

$$C_{9}$$

$$C_{1}$$

$$C_{1}$$

$$C_{1}$$

$$C_{2}$$

$$C_{3}$$

$$C_{4}$$

$$C_{5}$$

$$C_{6}$$

$$C_{7}$$

$$C_{1}$$

$$C_{8}$$

$$C_{1}$$

$$C_{1}$$

$$C_{2}$$

$$C_{3}$$

$$C_{4}$$

$$C_{5}$$

$$C_{6}$$

$$C_{7}$$

$$C_{8}$$

$$C_{9}$$

Bandpass filter

$$C_{3} = C_{4} = C$$

$$R_{1} = \frac{1}{A2\pi f_{0}C\alpha}$$

$$R_{2} = \frac{1}{\left(\frac{2}{\alpha^{2}} - A\right) 2\pi f_{0}C\alpha}$$

$$R_{5} = \frac{2}{\alpha 2\pi f_{0}C}$$

$$R_{5} = \frac{2}{\alpha 2\pi f_{0}C}$$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load program.			
2	Input filter design			
	specifications.			
	Corner or center frequency	f _o , Hz	1 A	f _o
	Midband gain	Α	A	Α
	Peaking factor (1/Q)	α	■ B	α
	Capacitor value	C, F	B	С
3	Select desired filter character-			
	istic and list elements.			
	Low pass		C	R ₁ ,
				C ₂ ,
				R ₃ ,
				R₄,
				C ₅
	High pass		D	C ₁ ,
				$R_{\scriptscriptstyle 2}$,
				C ₃ ,
				C₄,
				R₅
	Band pass		Œ	R ₁ ,
				R₂,
				C₃,
				C₄,
				R₅

Example 1:

Design a high-pass active filter with the following parameters:

$$f_0 = 10 \text{ Hz}$$

$$A = 10$$

$$\alpha = 1$$

$$C = 1 \mu F$$

Keystrokes:

Outputs:



9. BUTTERWORTH OR CHEBYSHEV FILTER DESIGN



This program computes component values for Butterworth or Chebyshev filters between equal terminations. Inputs are termination resistance, bandpass characteristics, attenuation at some out-of-band frequency, and, for the Chebyshev filter, allowable passband ripple.

Before the filter elements can be calculated, a normalized frequency must be computed from the desired cutoff or center frequency and band pass characteristics. The normalized frequency is computed by one of these formulas:

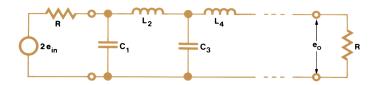
Low Pass High Pass

$$\omega_{n} = \frac{\omega_{0}}{\omega_{0}}$$
 $\omega_{n} = \frac{\omega_{0}}{\omega}$

Band Pass Band Elimination

$$\omega_n \, = \, \frac{\omega^2 \, - \, \omega_0{}^2}{BW\omega} \qquad \qquad \omega_n \, = \, \frac{\omega BW}{\omega_0{}^2 \, - \, \omega^2} \label{eq:omega_n}$$

The basic form of the filter is this low-pass prototype



whose elements are given by one of the following sets of formulas:

BUTTERWORTH

$$C_i = \frac{1}{\pi f_c R} \sin \frac{(2i-1) \pi}{2n}, \quad i = 1, 3, 5, ..., n-1$$

$$L_i = \frac{R}{\pi f_c} \sin \frac{(2i-1) \pi}{2n}, \quad i = 2, 4, 6, ..., n$$

where

$$n = INT$$

$$\frac{1 + \ln(2 \times 10^{-\Delta dB/10} - 1)}{2\ln(\omega/\omega_0)}$$

CHEBYSHEV

$$\begin{split} &C_i = \frac{G_i}{2\pi f_c R} \;, \quad i=1,\,3,\,5,\,...,\,n \\ &L_i = \frac{RG_i}{2\pi f_c}, \quad i=2,4,6,...,n-1 \end{split}$$

where

$$G_1 = \frac{2a_1}{\gamma}$$

$$G_i = \frac{4a_{i-1} a_i}{b_{i-1} G_{i-1}}, \quad i = 2, 3, 4, ..., n$$

$$\gamma = \sinh \left[\frac{\ln \left(\coth \frac{\epsilon}{40 \log e} \right)}{2n} \right]$$

$$a_i = \sin \frac{(2i-1) \pi}{2n}, \quad i = 1, 2, 3, ..., n$$

$$b_i = \gamma^2 + \sin^2 \frac{i\pi}{n}, \quad i = 1, 2, 3, ..., n-1$$

$$\epsilon = \left(10^{\Delta dB/10} - 1\right)^{\frac{1}{2}}$$

The filter order is found by using Newton's method to solve for n in the following formula:

$$(\omega + \sqrt{\omega^2 - 1})^{2n} + (\omega + \sqrt{\omega^2 - 1})^{-2n} = \frac{4}{\epsilon^2} (10^{\Delta dB/10} - 1) - 2$$

using

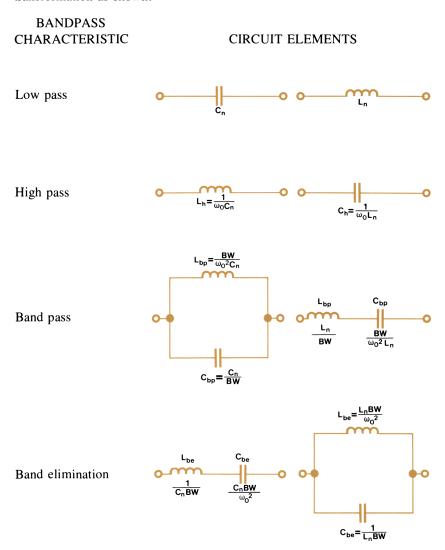
$$n = \frac{\ln \left[\frac{4}{\epsilon^2} (10^{\Delta dB/10} - 1) - 2 \right]}{\ln (\omega + \sqrt{\omega^2 - 1})}$$

as an initial guess.

The resulting value is then increased slightly:

$$n \leftarrow INT(n + 1)$$

Once the low-pass values have been calculated, if some other bandpass characteristic is desired, the components of the filter are changed by frequency transformation as shown.



To aid in deciphering the output, capacitors are output with a negative sign. A bit of thought may be necessary to determine whether the L-C's are connected in series or parallel.

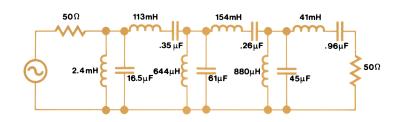
Note:

The program will give erroneous results if asked to compute filter order when ΔdB is small (i.e.: when $\Delta dB \sim Loss(\omega_0)$).

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load first program (EE1-09A1).			
2	Input termination resistance.	R, Ω	A	R
3	Input frequency information			
	for desired filter characteristic.			
	Low Pass	f _o , Hz	B	
	High Pass	f _o , Hz	■ B	
	Band Pass	BW, Hz	ENTER+	
		f _o , Hz	ø C	
	Band Elimination	BW, Hz	ENTER •	
		f _o , Hz	0	
4	For Chebyshev filter, continue			
	with steps 5, 7, and 9.			
	For Butterworth filter, continue			
	with steps 6, 7 and 8.			
5	Input bandpass information and			
	compute Chebyshev filter order.			
	Passband ripple	Ripple, dB		€
	Frequency at which			
	attenuation is specified	f ₁ , Hz	ENTER+	
	Desired attenuation	lpha, dB	D	n
6	Input bandpass information and			
	compute Butterworth filter order.			
	Frequency at which attenua-			
	tion is specified.	f₁, Hz	ENTER+	
	Desired attenuation	α, dB	8	n
7	Load second program			
	(EE1-09A2).			
8	Compute Butterworth filter			
	elements.		E	
9	Compute Chebyshev filter			
	elements.		D	

Example 1:

Design a 100 Hz wide Butterworth filter centered at 800 Hz with a 30 db attenuation at 900 Hz. R_0 is 50Ω . The termination resistance R is 50Ω .



Keystrokes:

Load card 1 (EE1-09A1)

50 A 100 ENTER+ 800

1 C 900 ENTER 30 E ——→

Load card 2 (EE1-09A2)

Outputs:

6.000+00 *** filter order

1.000+00 *** component 1

-16.48-06 *** capacitor

2.402-03 *** inductor

2.000+00 *** component 2

112.5-03 *** inductor

-351.7-09 *** capacitor

3.000+00 *** component 3

-61.49-06 *** capacitor

643.6-06 *** inductor

4.000+00 *** component 4

153.7-03 *** inductor

-257.5-09 *** capacitor

5.000+00 *** component 5

-45.02-06 *** capacitor

879.2-06 *** inductor

6.000+00 *** component 6

41.19-03 *** inductor

-960.8-09 *** capacitor

10. BODE PLOT OF BUTTERWORTH AND CHEBYSHEV FILTERS



This program provides gain, phase and group delay information for Bode plots of n-pole Butterworth or Chebyshev filters. A frequency transformation feature allows four types of filter characteristics: low pass, high pass, band pass, and band elimination. Frequency steps may be either linear (additive Δf) or logarithmic (multiplicative Δf).

The poles of an n-pole Butterworth filter are given by the following expression.

$$s_k = \sigma_k + j\omega_k = -\sin\left(\frac{2k-1}{3} \frac{\pi}{2}\right) - j\cos\left(\frac{2k-1}{3} \frac{\pi}{2}\right)$$
 (k=1, ..., n)

The poles of a Chebyshev filter are derived from Butterworth poles by the following procedure.

Let

$$\beta_{k} = \frac{1}{n} \sinh^{-1} \frac{1}{\epsilon}$$

Then the new poles are given by

$$s_k = \sigma_k \sinh \beta_k + i \omega_k \cosh \beta_k$$

The gain, phase and delay functions of a filter are given by the following expressions.

The network transfer function is

$$\begin{split} H(j\omega) &= \frac{K}{(j\omega - s_1) \; (j\omega - s_2) \; \dots \; (j\omega - s_n)} \\ &= \frac{K}{(M_1 \; \angle \; \theta_1) \; (M_2 \; \angle \; \theta_2) \; \dots \; (M_n \; \angle \; \theta_n)} \\ &= \frac{K}{M(\omega) \; \angle \; \theta(\omega)} \end{split}$$

in which K is a constant chosen such that

$$|H(j0)| = 1$$

The magnitude of the transfer function is

$$\left| H(j\omega) \right| \; = \; \frac{K}{\displaystyle \prod_{i=1}^{n} \; \sqrt{{\sigma_{i}}^{2} + (\omega - \omega_{i})^{2}}} \label{eq:hamiltonian}$$

and its phase is

$$\arg\left[H(j\omega)\right] = -\theta(\omega) = -\sum_{i=1}^{n} \tan^{-1} \frac{\omega - \omega_i}{-\sigma_1}$$

The normalized group delay is

$$t_{\rm g} = \frac{d}{d\omega} \left\{ \theta(\omega) \right\} = \sum_{\rm i=1}^{n} \frac{\sigma_{\rm i}}{\sigma_{\rm i}^2 + (\omega - \omega_{\rm i})^2}$$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load program.			
2	Select which filter.			
	Butterworth			
	# poles	n	A	
	Chebyshev			
	# poles	n	ENTER+	
	Passband ripple in dB	dB	1 A	
3	Select passband characteristic.			
	Low pass-cutoff frequency	f _o	В	
	High pass-cutoff frequency	f _o	I B	
	Band pass-Bandwidth	BW	ENTER+	
	Center frequency	f _o		
	Band elimination-Bandwidth	BW	ENTER+	
	Center frequency	f _o	0	
4	Select linear or logarithmic			
	frequency incrementation.			0-lin/1-log
5	Specify band of interest.			
	Minimum frequency	f ₁ , Hz	ENTER+	
	Maximum frequency	f₂, Hz	ENTER+	
	Frequency increment	Δf,Hz or ratio	D	

STEP	INSTRUCTIONS	INSTRUCTIONS INPUT DATA/UNITS KEYS		OUTPUT DATA/UNITS
6	Start computing.		•	f
	Magnitude of transfer function			20log H(jω),dB
	Angle of transfer function			arg{H(jω)}
	Normalized group delay			t _g
7	Step 6 is repeated auto-			
	matically for the band			
	specified.			

Example 1:

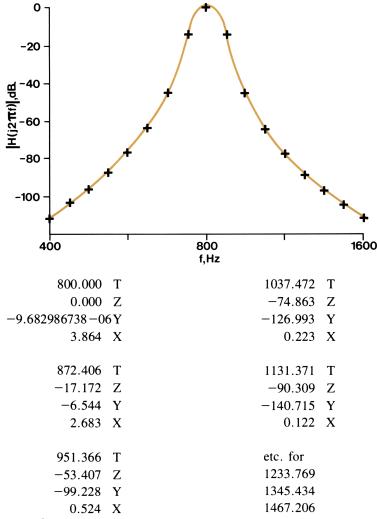
Plot the response of a 6-pole Butterworth band-pass filter with BW = 100, $f_0 = 800$. Make a logarithmic plot using steps of $2^{1/8}$ from 400 Hz to 1600 Hz.

Keystrokes:

1 □ 400 ENTER 1600 ENTER 1600

Outputs:

400.000	T	frequency 565.685	Т
-129.502		$ H(j2 \pi f) $ -90.309	Z
161.536	Y	$\angle H(j2 \pi f) $ 140.715	Y
0.027		group delay, sec. 0.122	X
0.027	Λ	group delay, see. 0.122	Λ
426 202	T	(16.004	T
436.203	T	616.884	T
-121.591	\mathbf{Z}	-74.863	Z
158.504	Y	126.993	Y
0.036	X	0.223	X
475.683	T	672.717	T
-112.727	Z	-53.407	Z
154.506	Y	99.228	Y
0.051	X	0.524	X
518.736	T	733.603	T
-102.519	Z	-17.172	Z
148.966	Y	6.544	Y
0.076	X	2.683	X



Example 2:

Plot the response of a 7-pole Chebyshev band-elimination filter of 5 Hz BW centered at 60 Hz with 3 dB passband ripple. Make a linear plot using steps of 0.5 Hz from 50 Hz to 61 Hz.

Keystrokes:



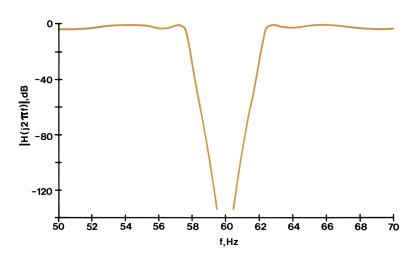
10-05

Outputs:

50.000	T	frequency 53.500	T
-2.997	Z	$mag \{H(s)\}, dB$ -1.027	Z
-84.017	Y	$arg\{H(s)\}, degrees$ -127.379	Y
4.506	X	group delay, sec. 7.737	X
50.500	T	54.000	T
-2.964	Z	-0.364	Z
-87.457	Y	-143.029	Y
4.559	X	9.239	X
51.000	T	54.500	T
-2.880	Z	0.000	Z
-91.347	Y	-164.525	Y
4.675	X	10.286	X
51.500	T	55.000	T
-2.730	Z	-0.478	Z
-95.842	Y	169.348	Y
4.881	X	9.368	X
52.000	T	55.500	T
-2.491	Z	-1.799	Z
-101.177	Y	143.391	Y
5.216	X	6.957	X
52.500	T	56.000	T
-2.140	Z	-2.932	Z
-107.732	Y	119.424	Y
5.742	X	5.448	X
53.000	T	56.500	T
-1.651	Z	-2.136	Z
-116.126	Y	88.980	Y
6.550	X	7.335	X

T	59.000	T	57.000
Z	-88.662	Z	-0.479
Y	103.950	Y	8.481
X	0.111	X	13.596
T	59.500	T	57.500
Z	-133.081	Z	-0.066
Y	96.633	Y	-122.266
X	0.024	X	37.279
T	60.000	T	58.000
Z	-1048.077	Z	-34.346
Y	-90.000	Y	127.620
X	1.985653756-15	X	1.179
T	60.500	T	58.500
Z	-133.598	Z	-59.784
Y	-96.577	Y	113.071
X	0.024	X	0.338

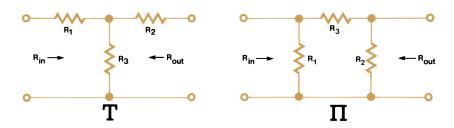
Note symmetry which indicates that we can reflect plot around 60 Hz.



11. RESISTIVE ATTENUATOR DESIGN



Both the T attenuator and the Π attenuator can be used to match between two resistive impedances, R_{in} and R_{out} . This program computes the minimum loss of the attenuator and values for the resistors R_1 , R_2 and R_3 which will yield an attenuator having any desired loss.



The minimum loss in decibels is given by

$$\text{Min Loss} = 10 \log \left(\sqrt{\frac{R_{in}}{R_{out}}} + \sqrt{\frac{R_{in}}{R_{out}}} - 1 \right)^{2}$$

where $R_{in} \ge R_{out}$

If N is the desired loss of the attenuator expressed as a ratio (loss in $dB = 10 \log N$), then for the T attenuator

$$R_3 = \frac{2\sqrt{N R_{in} R_{out}}}{N - 1}$$

$$R_1 = R_{in} \left(\frac{N+1}{N-1} \right) - R_3$$

$$R_2 = R_{out} \left(\frac{N+1}{N-1} \right) - R_3$$

and for the Π attenuator

$$R_{3} = \frac{1}{2} (N - 1) \left(\frac{R_{\text{in}} R_{\text{out}}}{N} \right)^{1/2}$$

$$\frac{1}{R_{1}} = \frac{1}{R_{\text{in}}} \left(\frac{N + 1}{N - 1} \right) - \frac{1}{R_{3}}$$

$$\frac{1}{R_{2}} = \frac{1}{R_{\text{out}}} \left(\frac{N + 1}{N - 1} \right) - \frac{1}{R_{3}}$$

Note: If the desired loss is less than the minimum loss, an error message will be generated.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load program.			
2	Input impedance levels.			
	Input circuit	R_{in},Ω	A	
	Output circuit	$R_out,\ \Omega$	B	
3	Compute minimum loss.		C	min loss, dB
4	Input desired loss and			
	compute resistances.			
	For T attenuator	Loss, dB	o	Loss
				R ₁
				R ₂
				R ₃
	For Π attenuator	Loss, dB	•	Loss
				R₁
				R ₂
				R ₃

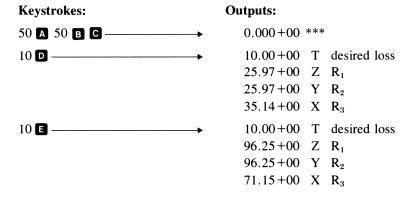
Example 1:

Compute element values for T and Π attenuators matching 75Ω to 50Ω with 6 dB loss.

Keystrokes:	Outputs:	
75 A 50 B C ──→	5.719+00 *** min loss	
6 □	6.000+00 T desired loss	;
	$43.34+00 Z R_1$	
	$1.572 + 00 Y R_2$	
	$81.97 + 00 X R_3$	
6 € — →	6.000+00 T desired loss	ì
	$2.386+03$ Z R_1	
	$86.52 + 00 \text{ Y } R_2$	
	$45.75 + 00 X R_3$	

Example 2:

Compute element values for T and Π attenuators matching 50Ω to 50Ω with 10 dB loss.



Notes

12. SMITH CHART CONVERSIONS



The distance between a point on a Smith Chart and its center may be measured by a number of parameters. The first three keys of this program allow conversion among some of the most commonly used ones: standing wave ratio, reflection coefficient, and return loss. The last two keys of this program convert between impedance and reflection coefficient.

The parameters

 σ = voltage standing wave ratio

SWR = standing wave ratio expressed in decibels

 ρ = reflection coefficient

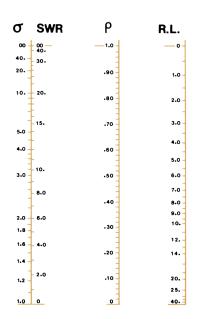
R.L. = return loss

are related as follows:

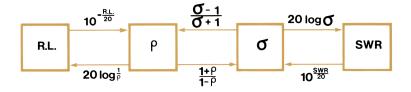
SWR = $20 \log \sigma$

R.L. = $20 \log \frac{1}{\rho}$

$$\sigma = \frac{1+\rho}{1-\rho}$$



These relationships are perhaps more clearly seen in this sketch:



For a system having characteristic impedance Z_0 , the impedance and reflection coefficient are related by

$$\Gamma = \rho \angle \phi = \frac{\frac{\mathbf{Z}}{Z_0} - 1}{\frac{\mathbf{Z}}{Z_0} + 1}$$

and

$$\mathbf{Z} = \mathbf{Z} \angle \theta = \mathbf{Z}_0 \frac{1 + \Gamma}{1 - \Gamma}$$

where

 Γ = complex reflection coefficient

$$\rho = |\Gamma|$$

$$\phi = \angle \Gamma$$

 $\mathbf{Z} = impedance$

$$Z = |Z|$$

$$\theta = \angle \mathbf{Z}$$

	0 - L L						
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS			
1	Load program.						
2	Convert among σ , SWR, $ ho$,						
	and R.L. as desired.						
	$\sigma \rightarrow SWR$	σ	f A	SWR			
	SWR $→σ$	SWR	A	σ			
	$\sigma \rightarrow \rho$	σ	■ B	ρ			
	$\rho \rightarrow \sigma$	ρ	В	σ			
	ρ→R.L.	ρ		R.L.			
	R.L.→ρ	R.L.	C	ρ			
3	Store characteristic						
	impedance.	Z _o					
4	Convert between Z and Γ						
	as desired.						
	Z→Γ	θ	ENTER+				
		Z	Œ	ϕ, ho			
	Γ→Z	φ	ENTER+				
		ρ	0	θ , Z			

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Convert a 6 dB SWR to σ .

Keystrokes:

Outputs:

6 A _____

 2σ

Example 2:

Convert a 7 dB return loss to SWR.

Keystrokes:

Outputs:



8.35 SWR

Example 3:

A 50Ω system is terminated with an impedance of 62 \angle 37°. What is the reflection coefficient?

Keystrokes:

Outputs:

Example 4:

A reflection coefficient of .5 \angle 7° is observed in a 72 Ω system. What is the impedance?

Keystrokes:

Outputs:

9.23 ***
$$\theta$$

Notes

13. TRANSMISSION LINE IMPEDANCE



This program computes high frequency characteristic impedance for five types of transmission line.

Transmission line configuration

Equation for Z_0

open two-wire line

$$Z_0 = \frac{120}{\sqrt{\epsilon}} \ln \left(\frac{2D}{d} \right)$$

single wire near ground

$$Z_0 = \frac{138}{\sqrt{\epsilon}} \log \left(\frac{4h}{d} \right)$$

balanced wires near ground

$$Z_0 = \frac{276}{\sqrt{\epsilon}} \log \left\{ \frac{2D}{d} \left[1 + \left(\frac{D}{2h} \right)^2 \right]^{-\frac{1}{2}} \right\}$$

wires in parallel near ground

$$Z_o = \frac{69}{\sqrt{\epsilon}} \log \left\{ \frac{4h}{d} \left[1 + \left(\frac{2h}{D} \right)^2 \right]^{+1/2} \right\}$$

coaxial line

$$Z_0 = \frac{60}{\sqrt{\epsilon}} \ln \frac{D}{d}$$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load program.			
2	Compute impedance of open			
	two-wire line.			
	Input wire spacing	D	ENTER+	
	wire diameter	d	ENTER+	
	relative permittivity	$\epsilon_{ m r}$	A	Z ₀ , Ω
3	Compute impedance of a			
	single wire near ground.			
	Input wire diameter	d	ENTER+	
	wire height	h	ENTER+	
	relative permittivity	€ _r	B	Z ₀ , Ω
4	Compute impedance of			
	balanced wires near			
	ground.			
	Input wire spacing	D	ENTER+	
	wire diameter	d	ENTER+	
	wire height	h	ENTER+	
	relative permittivity	$\epsilon_{ m r}$	C	Z ₀ , Ω
5	Compute impedance of wires			
	in parallel near ground.			
	Input wire spacing	D	ENTER+	
	wire diameter	d	ENTER+	
	wire height	h	ENTER+	
	relative permittivity	ε _r	D	Z ₀ , Ω
6	Compute impedance of			
	coaxial line.			
	Input inside diameter of			
	outer conductor	D	ENTER+	
	outside diameter of inner			
	conductor	d	ENTER+	
	relative permittivity	€r	3	Z ₀ , Ω

13-03

Example 1:

Compute Z_0 of RG-218/U coaxial cable. (D = .68 in., d = .195 in., ϵ_r = 2.3 (polyethylene)).

Keystrokes:

Outputs:

Example 2:

Compute Z_0 of open 2-wire line with D = 6 in., d = .0808 in., $\epsilon_r = 1$ (air).

Keystrokes:

Outputs:

6 ENTER
$$\cdot$$
 .0808 ENTER \cdot 1 A \rightarrow

$$A \rightarrow$$

Example 3:

Compute Z₀ of an air line consisting of a single .1285 inch wire 6 inches from a ground plane.

Keystrokes:

Outputs:

313.44 ***

Notes

14. MICROSTRIP CALCULATIONS



This program accepts conductor width w, dielectric thickness h, and relative permittivity ϵ_r , and computes relative phase velocity v_r and characteristic impedance Z_c for lossless line. The following formulas are used.

$$\epsilon_{eff} = \frac{\epsilon_{r} + 1}{2} + \frac{\epsilon_{r} - 1}{2} \left(1 + 10 \frac{h}{w} \right)^{\frac{1}{2}}$$

$$v_{r} = \frac{1}{\sqrt{\epsilon_{eff}}}$$

$$Z_{0} = \begin{cases} 60 \ln \left(8 \frac{h}{w} + \frac{w}{4h} \right), & \frac{w}{h} \leq 1 \\ \frac{120\pi}{\frac{w}{h} + 2.42 - 0.44 \frac{h}{w} + \left(1 - \frac{h}{w} \right)^{6}}, & \frac{w}{h} > 1 \end{cases}$$

$$Z_{c} = v_{r} Z_{0}$$

where

 $\epsilon_{\rm r}$ = relative permittivity of dielectric

 $\epsilon_{\rm eff}$ = effective permittivity of dielectric

h = dielectric thickness

w = width of microstrip

 v_r = relative phase velocity of lossless line

 Z_0 = characteristic impedance of corresponding air line, Ω

 Z_c = characteristic impedance of lossless microstrip, Ω

It then accepts the conductor thickness and computes a normalized conductor loss A.

$$A = \begin{cases} \frac{20}{\ln 10} \frac{h}{w Z_0} \frac{dB}{\Omega} \text{, uniform current distribution} \\ \frac{10}{\pi \ln 10} \frac{\left(8 \frac{h}{w} - \frac{w}{4h}\right) \left(1 + \frac{h}{w} + \frac{h}{w} \frac{\partial w}{\partial t}\right)}{Z_0 e^{Z_0/60}} \frac{dB}{\Omega} \text{, } \frac{w}{h} \leqslant 1 \\ \frac{Z_0}{720\pi^2 \ln 10} \left[1 + 0.44 \frac{h^2}{w^2} + \frac{6h^2}{w^2} \left(1 - \frac{h}{w}\right)^5\right] \\ \times \left[1 + \frac{w}{h} + \frac{\partial w}{\partial t}\right] \frac{dB}{\Omega} \text{, } \frac{w}{h} > 1 \end{cases}$$

where

$$\frac{\partial w}{\partial t} = \begin{cases} \frac{1}{\pi} \ln \frac{4\pi w}{t}, \frac{w}{h} \leq \frac{1}{2\pi} \\ \frac{1}{\pi} \ln \frac{2h}{t}, \frac{w}{h} > \frac{1}{2\pi} \end{cases}$$

Finally, the program accepts conductor resistivity ρ and frequency f and computes copper loss α_c , resistance per unit length R, and unloaded quality factor Q_0 using the following equations.

$$\alpha_0 = \frac{R_S A}{h}$$

$$\mu_0 = 4\pi \times 10^{-9} \text{ H/cm}$$

$$R_S = \sqrt{\pi f \mu_0 \rho}$$

$$R = 2R_S/w$$

$$\alpha_c = \frac{\alpha_0}{v_r}$$

$$Q_0 = \frac{20\pi}{\ln 10} \frac{f}{c v_r \alpha_c}$$

$$c = 3 \times 10^{10} \text{ cm/s}$$

Reference:

M.V. Schneider, "Microstrip Lines for Microwave Integrated Circuits," *Bell System Technical Journal*, 48, No. 5 (May–June 1969).

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load program.			
2	Input width of microstrip	w, cm	ENTER+	
	thickness of dielectric	h, cm	A	w/h
3	Input relative permit-			
	tivity and print relative			
	phase velocity and imped-			
	ance of lossless line.	€ _r	В	V _r
				Z _c
4	If a uniform current			
	distribution is desired,			
	skip to step 6.			
5	Input conductor thickness.	t, cm	G	Α
6	Input conductor resistivity.	ρ	O	
7	Input frequency and			
	print copper loss,			
	resistance per unit			
	length and unloaded Q.	f, Hz	g	$lpha_{ m c}$
				R
				Q_0

Example 1:

What are the characteristics of 50-mil microstrip on a 50-mil alumina ($\epsilon_r = 9.5$) substrate at 2GHz? Assume a line thickness of 1 mil and a conductor resistivity of 3 E -6.

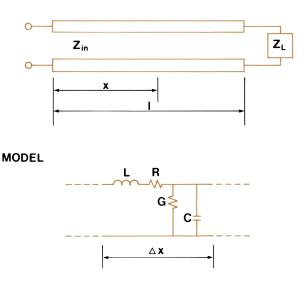
Example 2:

Repeat the above example, but assume a uniform current distribution.

15. TRANSMISSION LINE CALCULATIONS



This program computes the input impedance of lossy transmission line terminated in Z_L . The program provides an exact solution when the distributed line parameters R_0 (= $\sqrt{L/C}$), R, and G are given, and it provides an approximate solution when R_0 , copper loss and dielectric loss are given.



The transmission line shown has a lumped model composed of elements L, C, R, and G. From this model the following equations can be derived.

Let

$$R_0 = \sqrt{\frac{L}{C}}$$

$$r = \frac{R}{L} = \frac{vR}{R_0}$$

$$g = \frac{G}{C} = v R_0 G$$

$$\omega = 2\pi f$$

where

L = inductance/unit length

C = capacitance/unit length

R = resistance/unit length

G = conductance/unit length

 $v = 3 \times 10^8 v_r$

 v_r = relative phase velocity

f = frequency, Hz

Then

$$Z_{\rm in} = Z_0 \left(\frac{1 + \Gamma_L e^{-2\gamma l}}{1 - \Gamma_L e^{-2\gamma l}} \right)$$

where

$$\Gamma_{\rm L} = \frac{Z_{\rm L} - Z_0}{Z_{\rm L} + Z_0}$$

I = line length

 Z_L = impedance of termination

 $Z_0 = \text{characteristic}$ impedance of line = $\text{Re}\big\{Z_0\big\}$ + j $\text{Im}\big\{Z_0\big\}$

 γ = propagation constant of line = α + j β

 Z_0 and γ are computed differently depending on which solution is selected.

$$Re\left\{Z_{0}\right\} = \frac{R_{0}}{\sqrt{2(g^{2} + \omega^{2})}} \left[rg + \omega^{2} + \sqrt{(r^{2} + \omega^{2})(g^{2} + \omega^{2})}\right]^{\frac{1}{2}}$$

$$Im \big\{ Z_0 \big\} = \frac{\pm \ R_0}{\sqrt{2(g^2 \ + \ \omega^2)}} \left[- (rg \ + \ \omega^2) \ + \ \sqrt{(r^2 \ + \ \omega^2)(g^2 \ + \ \omega^2)} \right]^{1/2}$$

in which the + sign is chosen when $g \ge r$

and the - sign is chosen when g < r

and

$$\alpha = \frac{1}{\sqrt{2} v} \left[rg - \omega^2 + \sqrt{(r^2 + \omega^2)(g^2 + \omega^2)} \right]^{\frac{1}{2}}$$

$$\beta = \frac{1}{\sqrt{2}v} \left[\omega^2 - rg + \sqrt{(r^2 + \omega^2)(g^2 + \omega^2)} \right]^{\frac{1}{2}}$$

The approximate solution is

$$\operatorname{Re}\left\{Z_{0}\right\} = R_{0} \left[1 + \frac{1}{2} \left(\frac{\alpha_{C} - \alpha_{D}}{\beta_{0}}\right) \left(\frac{3\alpha_{D} + \alpha_{C}}{\beta_{0}}\right)\right]$$

$$\operatorname{Im}\left\{Z_{0}\right\} = R_{0} \left[\frac{\alpha_{D} - \alpha_{C}}{\beta_{0}}\right]$$

$$\alpha = \alpha_{C} + \alpha_{D}$$

$$\beta = \beta_{0} \left[1 + \frac{1}{2} \left(\frac{\alpha_{C} - \alpha_{D}}{\beta_{0}}\right)^{2}\right]$$

where

$$\alpha_{\rm C}=$$
 Copper loss, nepers/unit length $=\frac{1}{2}\,\frac{\rm R}{\rm R_0}$ $\alpha_{\rm D}=$ Dielectric loss, nepers/unit length $=\frac{1}{2}\,{\rm GR}.$ $\beta_0=\frac{\omega}{\rm V}$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load program.			
2	Inputs when R and G are			
	known.			
	Frequency	f, Hz	1 A	
	Relative phase velocity	V _r	ENTER+	
	Characteristic impedance of			
	lossless line	$R_{\scriptscriptstyle{0}},\Omega$	A	
	Line length	<i>l,</i> cm	В	
	Conductance of substrate			
	per unit length	G, S/cm	ENTER+	
	Resistance of line per			
	unit length	R, Ω /cm	C	
	Angle of terminating			
	impedance	∠Z _L , deg	ENTER+	
	Magnitude of terminating			
	impedance	$ Z_L , \Omega$	Œ	$ heta_{in}$
				Z_{in}
3	Inputs when α_{C} and α_{D}			
	are known.			
	Frequency	f, Hz	1 A	
	Relative phase velocity	V _r	ENTER+	
	Characteristic impedance			
	of lossless line	R_{o},Ω	A	
	Line length	I, cm	В	
	Dielectric loss per unit length	$lpha_{ extsf{D}}$	ENTER+	
	Copper loss per unit length	$lpha_{ m c}$	D	
	Angle of terminating			
	impedance	∠Z _L , deg	ENTER+	
	Magnitude of terminating			
	impedance	$ Z_{\scriptscriptstyleL} ,\Omega$	•	$ heta_{in}$
				Z_{in}

Example 1:

A transmission line has the following properties:

 $R = 1.2664 \Omega / cm$

G = 0.000 041 87 Siemens/cm

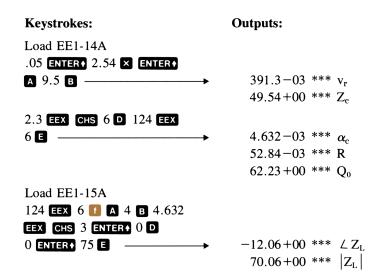
 $R_0 = 55 \Omega$

 $v_{\rm r}\,=0.85$

What is the input impedance of 3.5 cm of this line at 2 GHz if it is terminated in $Z_L = 75 \ L - 30^{\circ}$?

Example 2:

A 4-cm gold ($\rho = 2.3 \,\mu\Omega$ /cm) microstrip line of 50-mil width is on a 50-mil alumina ($\epsilon_r = 9.5$) substrate. Assuming a uniform current distribution and zero dielectric loss, what is the input impedance of the line at 124 MHz when it is terminated in 75 Ω ?



Notes

16. UNILATERAL DESIGN: FIGURE OF MERIT, MAXIMUM UNILATERAL GAIN, GAIN CIRCLES



This program computes u, G_u , G_{min} , G_{max} , G_0 , G_{1max} , and G_{2max} from a transistor's s-parameters. It also computes r_{0i} and ρ_{0i} from $G_i \leq G_{imax}$ (i=1, 2).

When designing a transistor amplifier with the aid of s-parameters, the often valid assumption that the reverse-transmission parameter s_{12} may be neglected leads to simplified equations. A transistor for which s_{12} is negligible is said to be a "unilateral device." The unilateral figure of merit u may be used to determine the reasonableness of the unilateral assumption:

$$u = \frac{\left| s_{11} \ s_{12} \ s_{21} \ s_{22} \right|}{\left| (1 - \left| s_{11} \right|^2)(1 - \left| s_{22} \right|^2) \right|}$$

Clearly, the unilateral assumption is more nearly correct for u near zero.

The maximum unilateral transducer power gain is given by

$$G_{u} = \frac{\text{Power delivered to load}}{\text{Power available from source}}$$
$$= \frac{\left|s_{21}\right|^{2}}{\left|(1 - \left|s_{11}\right|^{2})(1 - \left|s_{22}\right|^{2})\right|}$$

Using the unilateral figure of merit we can place limits on the actual transducer power gain:

$$G_{\min} = G_{\mathrm{u}} \frac{1}{(1+\mathrm{u})^2}$$

$$G_{\text{max}} = G_{\text{u}} \frac{1}{(1 - \text{u})^2}$$

When input and output impedances are conjugately matched, the transducer power gain is

$$G_{u} = G_{0} \cdot G_{1} \cdot G_{2}$$

where

$$G_u$$
 = transducer power gain = $\frac{\text{Power delivered to load}}{\text{Power available from source}}$

$$G_0 = \left| s_{21} \right|^2$$
 = transducer gain for Z_0 input and output impedances

$$G_{1max} = \frac{1}{1 - \left|s_{11}\right|^2} = \text{gain contribution from change of source impedance from } Z_0 \text{ to } s_{11}^*$$

$$\begin{aligned} G_{2max} &= \frac{1}{1 - \left|s_{22}\right|^2} = \text{gain contribution from change of load} \\ &\text{impedance from } Z_0 \text{ to } s_{22}^* \\ &s_{ij}^* = \text{complex conjugate of } s_{ij}. \end{aligned}$$

For source and load impedances other than s_{11}^* and s_{22}^* , G_1 and G_2 are less than the maximum values given above. The loci of points on a Smith chart representing values of source or load impedance which yield values of G_1 or G_2 less than G_{1max} or G_{2max} are circles. The center of a constant gain circle is in the direction of s_{ii}^* (i=1,2) at a distance

$$r_{oi} = \frac{G_i \ s_{ii}}{1 + G_i |s_{ii}|^2}$$

from the origin.

The radius of the circle is

$$\rho_{oi} = \frac{\sqrt{1 - G_i(1 - |s_{ii}|^2)}}{1 + G_i |s_{ii}|^2}$$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load program.			
2	Input magnitude of			
	s-parameters for $i = 1, 2,$			
	j=1, 2.			
	Magnitude	S _{ij}	ENTER+	
	Designation	ij	A	
3	Compute			
			B	u
				G_{u}
				G_{min}
				G_{max}
				G₀
				G_{1max}
				G_{2max}

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
4	Input desired gain			
	(≤G _{1max}) and compute loca-			
	tion * of center of gain circle			
	on input plane.	G₁, dB	G	r ₀₁
				$ ho_{01}$
5	Input desired gain			
	(≤G _{2max}) and compute loca-			
	tion * of center of gain circle			
	on output plane.	G₂, dB	I C	r ₀₂
				$ ho_{02}$
	*Note: These points are			
	located at a distance roi from			
	the origin of the Smith chart			
	in the direction of s _{ii} .*			

Example 1:

An HP35876E option 100 transistor operating at 4 GHz has the following s-parameters:

$$S = \begin{bmatrix} .51 \ \angle 154^{\circ} & .09 \ \angle 26^{\circ} \\ 1.4 \ \angle 22^{\circ} & .60 \ \angle -58^{\circ} \end{bmatrix}$$

What is the unilateral figure of merit?

What is the maximum unilateral transducer power gain?

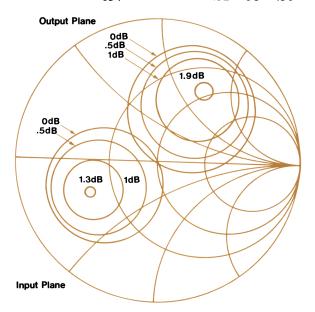
What is the range of transducer gain due to the fact that s₁₂ is not zero?

What are G_0 , G_{1max} , and G_{2max} ?

Draw 0 dB, .5 dB, and 1 dB constant gain circles on input and output planes.

Keystrokes: Outputs:

	6.91 ***	Gactual max
	2.92 ***	
	1.31 ***	G_{1max}
	1.94 ***	G_{2max}
0 C	0.40 ***	r_{o1}
	0.40 ***	$ ho_{ m o1}$
.5 C	0.44 ***	r_{o1}
	0.32 ***	$ ho_{ m o1}$
1 C	0.48 ***	
	0.20 ***	$ ho_{01}$
0 f C —	0.44 ***	
	0.44 ***	$ ho_{02}$
.5 [] []	0.48 ***	
	0.38 ***	$ ho_{ m o2}$
1 [C ———	0.52 ***	
	0.30 ***	$ ho_{02}$



17. BILATERAL DESIGN: STABILITY FACTOR, MAXIMUM GAIN, OPTIMUM MATCHING

$$\begin{array}{cccc} & \text{BILATERAL DESIGN: K, } G_{max}, \Gamma_{opt} & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & \\ & & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & \\ & & \\ & \\ & & \\ &$$

Sometimes s_{12} is not sufficiently small that it may be neglected in transistor amplifier design. In this case it is necessary to compute a stability factor K and use different design approaches depending on its value. The stability factor is defined by the equation

$$K = \frac{1 + \left| \Delta \right|^2 - \left| s_{11} \right|^2 - \left| s_{22} \right|^2}{2 \left| s_{21} \right| s_{12}}$$

where

s_{ij} are s-parameters

and

$$\Delta = S_{11} S_{22} - S_{21} S_{12}$$

For K < 1 the amplifier is potentially unstable and the designer must choose input and output matching networks very carefully (see program EE1-18A). For K > 1 the amplifier is unconditionally stable and this program may be used to compute the maximum gain available and the load and source reflection coefficients which yield the maximum gain.

Maximum gain is computed using the relation

$$G_{\text{max}} = \frac{|s_{21}|}{|s_{12}|} (K \pm \sqrt{K^2 - 1})$$

in which the plus sign is used when the quantity

$$B_1 = 1 + |s_{11}|^2 - |s_{22}|^2 - |\Delta|^2$$

is negative and the minus sign is used when B₁ is positive.

The second portion of this program computes values of source and load reflection coefficients required to conjugately match the transistor using the equations

$$\Gamma_{ms} = C_1 * \left[\frac{B_1 \pm \sqrt{B_1^2 - 4 |C_1|^2}}{2 |C_1|^2} \right]$$

$$\Gamma_{\text{ml}} = C_2^* \left[\frac{B_2 \pm \sqrt{B_2^2 - 4 |C_2|^2}}{2 |C_2|^2} \right]$$

where

$$C_1 = S_{11} - \Delta S_{22}^*$$

 $C_1^* = \text{complex conjugate of } C_1$

$$C_2 \, = \, s_{22} \, - \, \Delta s_{11} *$$

 C_2^* = complex conjugate of C_2

$$B_1 = 1 + |s_{11}|^2 - |s_{22}|^2 - |\Delta|^2$$

$$B_2 = 1 + |s_{22}|^2 - |s_{11}|^2 - |\Delta|^2$$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load program.			
2	Input s-parameter matrix			
	(ij=11, 12, 21, 22).			
	Angle of s _{ij}	$ heta_{ij}$, deg	ENTER+	
	Magnitude of s _{ij}	s _{ij}	ENTER*	
	Subscript	ij	A	Sij
3	Compute stability factor and			
	maximum gain.*		В	K
				G _{max} , dB
4	Compute angle and magnitude			
	of source reflection			
	coefficient.			$ heta_{\sf ms}$
				$ \Gamma_{\sf ms} $
5	Compute angle and magnitude			
	of load reflection			
	coefficient.		C	$ heta_{ml}$
				$ \Gamma_{m I} $
	*If k<1, this calculation			
	causes an error.			

Example:

Design a maximum-gain amplifier using a transistor having the following s-parameters.

$$s_{11} = 0.277 \ \angle -59^{\circ}$$

 $s_{12} = 0.078 \ \angle 93.0^{\circ}$
 $s_{21} = 1.920 \ \angle 64^{\circ}$
 $s_{22} = 0.848 \ \angle -31^{\circ}$

Keystrokes:

Outputs:

$$21$$
 A 31 CHS ENTER • $.848$ ENTER •

135.4+00 ***
$$\angle \Gamma_{ms}$$
729.8-03 *** $|\Gamma_{ms}|$

$$33.85+00 *** \angle \Gamma_{ml}$$

 $951.1-03 *** |\Gamma_{ml}|$

Notes

18. BILATERAL DESIGN: GAIN AND STABILITY CIRCLES, LOAD AND SOURCE MAPPING



If it is desired to build an amplifier having gain less than the maximum possible for the transistor to be used, a gain circle is constructed. This circle shows all possible loads for the output that yield the desired power gain. When a load on this gain circle is selected, the load and source mapping routine may be used to compute the new source reflection coefficient required.

This program computes the center

$$\mathbf{r}_{02} = \left[\frac{\mathbf{G}}{1 + \mathbf{D}_2 \; \mathbf{G}} \right] \; \mathbf{C}_2 *$$

and radius

$$\rho_{02} = \frac{(1 - 2K |s_{12}s_{21}| G + |s_{12}s_{21}|^2 G^2)^{\frac{1}{2}}}{1 + D_2 G}$$

where

$$G = \frac{G_p}{G_0}$$

 G_p = desired gain

 G_0 = maximum transducer gain = $|s_{21}|^2$

$$C_2 = S_{22} - \Delta S_{11} *$$

$$D_2 = |s_{22}|^2 - |\Delta|^2$$

$$\Delta = s_{22} s_{11} - s_{21} s_{22}$$

When a two-port network is terminated in a load having reflection coefficient Γ_L , the source reflection coefficient for a conjugate input match becomes

$$\Gamma_{\rm ms} = \left[\begin{array}{c} s_{11} + \frac{s_{12} s_{21}}{\frac{1}{\Gamma_{\rm L}} - s_{22}} \end{array} \right]^*$$

Similarly, when the source reflection coefficient of a two-port network is Γ_s , the output reflection coefficient for a conjugate output match becomes

$$\Gamma_{\rm ml} = \left[s_{22} + \frac{s_{12} s_{21}}{\frac{1}{\Gamma_{\rm S}} - s_{11}} \right]^*$$

This routine accepts Γ_L or Γ_S and computes the corresponding source or load reflection coefficient. A typical use is to determine which area defined by a stability circle is the stable or unstable region (for stable operation, Γ_L must be such that $|\Gamma_{ms}| < 1$ and Γ_S must be such that $|\Gamma_{ml}| < 1$).

For the potentially unstable amplifier (stability factor K < 1), it is necessary to avoid values of source and load reflection coefficients which could cause oscillations. The boundaries between stable and unstable regions are circles on the input and output planes.

The centers of the stability circles are located at:

$$r_{si} = \frac{C_i^*}{|s_{ii}|^2 - |\Delta|^2}$$

where

 r_{s1} = location of center of stability circle on input plane

 r_{s2} = location of center of stability circle on output plane

$$C_1 = s_{11} - \Delta s_{22}^*$$

$$C_2 = S_{22} - \Delta S_{11}^*$$

$$\Delta = s_{11} s_{22} - s_{21} s_{12}$$

The radii of the stability circles are:

$$\rho_{\rm si} = \frac{|s_{12} s_{21}|}{|s_{\rm ii}|^2 - |\Delta|^2}$$

where

 $\rho_{\rm s1}$ = radius of stability circle on input plane

 $\rho_{\rm s2}$ = radius of stability circle on output plane

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	First run EE1-17A, then			
	load this program.			
2	Perform any or all of the			
	following steps in any order.			
3	Input desired gain less than			
	G _{max} and compute location			
	and radius of gain circle.	G₅, dB	Α	۷r
				r
				ρ
4	Input load reflection coefficient			
	and compute new source			
	reflection coefficient.	∠ Γ _ι , deg	ENTER ◆	
		17	В	$oldsymbol{L} \Gamma_{ms}$
				$ \Gamma_{\sf ms} $
5	Input source reflection coef-			
	ficient and compute new load			
	reflection coefficient.	ے $\Gamma_{ extsf{s}}$, deg	ENTER+	
		$ \Gamma_{s} $	■ B	$oldsymbol{L} \Gamma_{m i}$
				$ \Gamma_{m_1} $
6	Compute location and radius			
	of stability circles on input			
	(i=1) or output (i=2) planes.	i	0	∠ r _{si}
				r _{si}
				$ ho_{si}$

Example 1:

A gain of 10 dB is desired from an amplifier using a transistor whose s-parameter matrix is

$$S = \begin{bmatrix} .277 & \angle -59^{\circ} & .078 & \angle 93^{\circ} \\ \\ 1.92 & \angle 64^{\circ} & .848 & \angle -31^{\circ} \end{bmatrix}$$

Where is the center of the 10 dB gain circle and what is its radius?

Keystrokes: Outputs: Load EE1-17A 59 CHS ENTER ↑ .277 ENTER ↑ 11 A 93 ENTER ↑ .078 ENTER ↑ 12 A 64 ENTER 1.92 ENTER 1.92 € 1.92 A 31 CHS ENTER ↑ .848 ENTER ↑ 22 A B ——— 1.033+00 *** K 12.81+00 *** G_{max} $\longrightarrow 135.4+00 *** \theta_{\rm ms}$ 729.8-03 *** Γ_{ms} $33.85+00 *** \theta_{ml}$ 951.1-03 *** Γ_{ml} Load EE1-18A 10 A ——— $33.85+00 *** \angle r_{02}$ $781.2 - 03 *** |r_{02}|$ $214.2 - 03 *** \rho_{02}$

Example 2:

We have determined that the 10 dB gain circle is located at $r_{02} = .781 \angle 33.85^{\circ}$ with a radius of $\rho_{02} = .214$. If we pick a load reflection coefficient of $(|r_{02}| - \rho_{02}) \angle r_{02} = .567 \angle 33.85^{\circ}$, what source reflection coefficient is required?

Keystrokes: Outputs:

Continuing from Example 1,
$$33.85 \text{ ENTER} \cdot .567 \text{ B} \longrightarrow 93.33 + 00 *** \bot \Gamma_{ms}$$

$$276.0 - 03 *** | \Gamma_{ms}|$$

Example 3:

Construct stability circles for a transistor having the following s-matrix.

$$S = \begin{bmatrix} .385 \ \angle -55^{\circ} & .045 \ \angle 90^{\circ} \\ \\ 2.7 \ \angle 78^{\circ} & .89 \ \angle -26.5^{\circ} \end{bmatrix}$$

Keystrokes

Outputs:

Load EE1-17A

CLX (Clear "Error")

Load EE1-18A

29.88+00 ***
$$\angle$$
 r_{s2}
1.178+00 *** $|$ r_{s2} $|$
192.6-03 *** ρ _{s2}

Program Listings

The following listings are included for your reference. A table of keycodes and keystrokes corresponding to the symbols used in the listings can be found in Appendix E of your Owners Handbook.

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	Load and Source Mapping	.L18-01

Network Transfer Functions—Input

001	*LBLA	Inpu	t f	857	1/8		
802	CLRG			9 58	9		
887	2			65 9	e		
004	x			868	CHS		
865	P:			061	GT02		Pass $(\omega C)^{-1} \angle -90$ to
886	x	1			#LBLe		LBL 2.
807	STOR	Store	9.63	862			
		31016	ε ω	963	6SB0		1 (210
008	1	- 1		0€4	CHS		Pass $\frac{1-\omega^2 LC}{\omega C} \angle -90$ to
909	ST01	1 1	r 1	965	X#Y		ωC
818	ST07	lſu⊧l	[1∠0 0 0 1∠0]	966	1/X		LBL 2.
811	CLX	الأحا	[0 1∠0]	867	XZY		
012	RTN				*LBL2		
013	*LELE	- 1		869			
614	0				GSB7		
015	GT01	اما	D / O I DI . 4	878	RCLC		[, ,]
		Pass	R ∠ 0 to LBL 1.	871	RCLE		ا بدا ' ا با
016	*LBLC			072	RCL9		[4] [←] <u>+</u> ₁ [4]
017	RCL0	1		873	1/8		$[\mathbf{Y}] \leftarrow \begin{bmatrix} 1 & 0 \\ \frac{1}{Z} & 1 \end{bmatrix} [\mathbf{Y}]$
e 18	×			874	RCLA		L 3
0 19	9	l		875	CHS		
820	e	l		876	ESB9		
821	GT01	Page	ωL ∠ 90 to LBL 1.				
822	*LBLD	r dss	to EBL 1.	877	ST05		
		ı		€78	₽↓		
023	RCL@	ı		879	ST06		
824	x	l		880	RCLE		
825	1/X	ĺ		881	RCLD		
826	9			682	RCL9		
627	e			883	1/8		
628	CHS						
029	GT01	D	$(\omega C)^{-1} \angle -90$ to	884	RCLA		
636	#LELE			885	CHS		
		LBL	1	98€	€SB9		
031	XZY	1	631	887	ST07		
632	€SB@	Pass	$\frac{\omega L}{1 - \omega^2 LC} \angle 90 \text{ to}$	986	R↓		
03 3	*LBL1		1 – ω² LC	889	ST08		
034	GSB7	LBL	1.	898	CLX		
035	RCLC	ı		091	RTH		
03€	STO2	1					INPUT: y = Z
0 37	RCLB		C7		*LBL7		x = \(Z
638	ST01	1	$\leftarrow \begin{bmatrix} 1 & z \\ 0 & 1 \end{bmatrix} [\mathbf{q}]$	893	STOA		^
639	RCLE	u •	∸। ि प ो	694	X≇Y		
		'-'	[0 1]	895	ST09		
040	ST04			896	RCL5		
841	RCLD			097	RCL €		Compute and store
842	ST03	ľ		898	ESB9		$\mathbf{q}_{11} + Z\mathbf{q}_{21}$
843	CLX	1		899	RCL2		4
844	RTN			100	RCL1		
845	*LBL&						
846	6			101	esb8		ı
847	GT02	1_	D / O I D . O	102 103	STOP		·
		Pass	R ∠ 0 to LBL 2.		R↓		
048	*LBLc			184	STOC		
649	RCL®			105	RCLA		
858	×			10€	RCL9		
051	9			107	RCL7		
052	e			188	RCL8		
65 3	GTO2	Pass	ω L \angle 90 to LBL 2.	109	6SB9		Compute and store
854	*LBL d	' "		110	RCL4		U ₁₂ + Z U ₂₂ .
955	RCLO		_	111	RCL3		712 - 422.
₽5€	X	1					
636				112	esbe		
-	1.	Ta 1-	REGI	STERS	To		lo lo
ο ω	1 y 11	² ∠ y ₁₁ ³ y	I ₁₂ 4 ∠ y ₁₂	⁵ પ્ 21	⁶ ∠ प 21	7 Y 22	⁸ ∠ y ₂₂
SO	S1	S2 S3	S4	S5	S6	S7	S8 S9
150	1 "	33	34	33	36	l3′	
A / 7	В		Tc .	D .		E /	
^ LZ	اً	U _{11 new}		प 12new	,	_ ∠¶ _{12new}	ľ

114 115 ST 116 F 117 *LE 118 119 120 121 122 > 123 124	TOD R	Subroutine to add compounders.					
127 128 129 k 130 *LE 131 132 133 134 135 136 k 137 *LE 138 139 LS	R↑ →P +P +P +P +P ++ ++ ++ ++ ++ +	Subroutine to multiply complex numbers. INPUT: y = b x = a					
142 X 143 LS 144 145 146 147 148 0 149 150 151	X CTY CTY X X 1 	OUTPUT: $y = \frac{\omega a}{1 - \omega^2}$	ab 				
		LABELS		FLAGS		SET STATUS	
A f	Series R C S		Series tank	0	FLAGS	TRIG	DISP
a t	Shunt R C S	Hant E Shunt C	Shunt L-C	1	ON OFF	DEG 🗷	FIX 🗷
0 Used 1		osed	4	2	1 1	GRAD □ RAD □	SCI □ ENG ⊠ n 3
	' / L	Jsed ⁸ CADD	CMULT	3	3 □ 🛣		n_3_

Network Transfer Functions —Output

991	*LBLA	Input Z _L	057 RCL2	1
882	ST09	I IIIput ZL	058 RCL1	l
903	XZY	1	059 RCL4	
004	STOA		0€0 RCL3	
995	CLX		061 GSB6	
		1	062 RCLA	
986	R/S			1
007	*LBLB	Compute Z _{in}	063 RCL9	
888	GSB4		064 R↑	
		•	065 CHS	1
009	RCLB	l .		
1 616	1/X		966 R†	
011	RCLI		067 1/X	
			068 XZY	
012	CHS			
013	GSB9		069 GSB9	1
014	6105	1	070 X2	
		0	071 RCLC	
015	*LBLC	Compute V ₂ /V ₁		
01€	RCL2		072 x	
017	RCL1		073 F0?	
				1
918	RCL4	1		1
019	RCL3	1	075 RTN	
828		1	07€ *LBL5	IF flag 0
	CSB6	I	077 F0?	THEN go to LBL 0
921	RCLA	1		
022	RCL9		078 GTO0	ELSE
023		1	079 *LBL1	Display y and x
	R†	1	080 XZY	alternately.
824	CHS	I		-1.0.1.0.0.7.
025	R†	1	081 R/S	
02€			062 GTO1	1
	1/X		1 11 11 11 11 11 11 11 11 11 11 11 11 1	D.:
027	XZY			Print y and x.
628	GSB9		884 X≇Y	
029		1	085 PRTX	
	GT05		986 X≢Y	
030	*LBLD	Compute I ₂ /I ₁		1
931	RCL6		087 PRTX	1
			088 RTN	1
932	RCL5		089 *LBL4	
033				
000	RCL8			Compute and store
		1	090 RCL6	
034	RCL7		090 RCL6	Z _L U ₂₁ + U ₂₂ .
034 035	RCL7 GSB6		090 RCL6 091 RCL5	
034 035 036	RCL7		090 RCL6 091 RCL5 092 RCL8	
034 035 036	RCL7 GSB6 1/X		090 RCL6 091 RCL5	
034 035 03€ 03?	RCL7 GSB6 1/X X≇Y		090 RCL6 091 RCL5 092 RCL8 093 RCL7	
034 035 036 037 038	RCL7 GSB6 1/X XZY CHS		090 RCL6 091 RCL5 092 RCL8 093 RCL7 094 GSB6	
034 035 03€ 03?	RCL7 GSB6 1/X X≇Y		898 RCL6 891 RCL5 892 RCL8 893 RCL7 894 GSB6 895 STOB	
034 035 03€ 037 038 039	RCL7 GSB6 1/X XZY CHS XZY		090 RCL6 091 RCL5 092 RCL8 093 RCL7 094 GSB6	
034 035 036 037 038 039	RCL7 GSB6 1/X XZY CHS XZY CHS		898 RCL6 891 RCL5 892 RCL8 893 RCL7 894 GSB6 895 STOB 896 R4	Z _L ų ₂₁ + ų ₂₂ .
034 035 036 037 038 039 040	RCL7 GSBC 1/X XZY CHS XZY CHS GT05		999 RCL6 991 RCL5 992 RCL8 993 RCL7 994 GSB6 995 STOB 896 R4 897 STO1	
034 035 036 037 038 039 040 041	RCL7 GSB6 1/X XZY CHS XZY CHS	Compute P ₂ /P ₁	898 RCL6 891 RCL5 892 RCL8 893 RCL7 894 SSB6 895 STOB 896 R4 897 STOI 898 RCL2	Z _L ų ₂₁ + ų ₂₂ .
034 035 036 037 038 039 040	RCL7 GSB6 1/X X2Y CHS X2Y CHS CHS 4LBLE	 Compute P ₂ /P ₁	898 RCL6 891 RCL5 892 RCL8 893 RCL7 894 GSB6 895 STOB 896 R4 897 STOI 898 RCL2 899 RCL1	Z _L ų ₂₁ + ų ₂₂ .
934 935 936 937 938 939 949 941 942	RCL7 \$586 1/X X2Y CMS X2Y CMS \$705 \$4LBLE \$584	Compute P ₂ /P ₁	898 RCL6 891 RCL5 892 RCL8 893 RCL7 894 GSB6 895 STOB 896 R4 897 STOI 898 RCL2 899 RCL1	Z _L ų ₂₁ + ų ₂₂ .
034 035 036 037 038 039 040 041 042 043	RCL7 GSB6 1/X X2Y CHS X2Y CHS GTO5 #LBLE GSB4 RCLB	Compute P ₂ /P ₁	898 RCL6 891 RCL5 892 RCL8 893 RCL7 894 GSB6 895 STOB 896 R4 897 STOI 898 RCL2 899 RCL1 180 RCL4	Z _L ų ₂₁ + ų ₂₂ .
034 035 036 037 038 039 040 041 042 043 044	RCL7 GSB6 1/X XZY CHS XZY CHS GCD5 *LBLE GSB4 RCLB 1/X	Compute P ₂ /P ₁	898 RCL6 891 RCL5 892 RCL8 893 RCL7 894 GSB6 895 STOB 896 R4 897 STOI 898 RCL2 899 RCL1 1808 RCL4 181 RCL3	Z _L ų ₂₁ + ų ₂₂ .
034 035 036 037 038 039 040 041 042 043	RCL7 GSB6 1/X X2Y CHS X2Y CHS GTO5 #LBLE GSB4 RCLB	Compute P ₂ /P ₁	898 RCL6 891 RCL5 892 RCL8 893 RCL7 894 GSB6 895 STOB 896 R4 897 STOI 898 RCL2 899 RCL1 188 RCL4 181 RCL3	Z _L ų ₂₁ + ų ₂₂ .
034 035 036 037 039 040 041 042 043 044 045	RCL7 \$SB6 1/X X2Y CHS X2Y CHS \$105 \$LBLE \$SB4 RCLB 1/X RCLI	Compute P ₂ /P ₁	898 RCL6 891 RCL5 892 RCL8 893 RCL7 894 GSB6 895 STOB 896 R4 897 STOI 898 RCL2 899 RCL1 1808 RCL4 181 RCL3	Z _L ų ₂₁ + ų ₂₂ .
934 935 936 937 938 949 941 942 943 944 945 946	RCL7 \$SB6 11/X XZY CHS XZY CHS \$CTOS #LBLE \$SB4 RCLB 1/X RCLI CHS CHS	Compute P ₂ /P ₁	898 RCL6 891 RCL5 892 RCL8 893 RCL7 894 GSB6 895 STOB 896 R4 897 STOI 898 RCL2 899 RCL1 180 RCL4 181 RCL3 182 *LBL6 183 STOE	Z _L ų ₂₁ + ų ₂₂ .
934 935 938 939 949 941 942 943 944 945 946	RCL7 GSB6 1/X X2Y CHS X2Y CHS GCD5 *LBLE GSB4 RCLB 1/X RCLI CHS GSB9	Compute P ₂ /P ₁	898 RCL6 891 RCL5 892 RCL8 893 RCL7 894 GSB6 895 STOB 896 R4 897 STOI 898 RCL2 899 RCL1 180 RCL4 181 RCL3 182 *LBL6 183 STOE	Z_ U 21 + U 22. Compute Z_ U 11 + U 12
934 935 936 937 938 949 941 942 943 944 945 946	RCL7 \$SB6 11/X XZY CHS XZY CHS \$CTOS #LBLE \$SB4 RCLB 1/X RCLI CHS CHS	Compute P ₂ /P ₁	999 RCL6 991 RCL5 992 RCL8 993 RCL7 994 GSB6 995 STOB 996 R4 997 STO1 998 RCL2 999 RCL1 180 RCL4 181 RCL3 182 ±BL6 183 STOE 184 R4 185 STOD	Z _L ų ₂₁ + ų ₂₂ .
934 935 936 937 938 939 940 941 942 943 944 945 946 947	RCL7 \$SB6 1/X X2Y CHS X2Y CHS \$T05 *LBLE \$GSB4 RCLB 1/X RCLI CHS \$SB9 +R	Compute P ₂ /P ₁	898 RCL6 891 RCL5 892 RCL8 893 RCL7 894 GSB6 895 STOB 896 R4 897 STOI 898 RCL2 899 RCL1 180 RCL4 181 RCL3 182 *LBL6 183 STOE	$Z_L \mathbf{q}_{21} + \mathbf{q}_{22}$. Compute $Z_L \mathbf{q}_{11} + \mathbf{q}_{12}$.
934 935 936 937 938 949 941 942 943 944 945 946 947 948	RCL7 GSB6 11/X X2Y CHS X2Y CHS GTO5 #LBLE GSB4 RCLB 11/X RCLI CHS GSB9 +R RCLA	Compute P ₂ /P ₁	898 RCL6 891 RCL5 892 RCL8 893 RCL7 894 GSB6 895 STOB 896 R4 897 STOI 898 RCL2 899 RCL1 180 RCL4 181 RCL3 182 #LBL6 183 STOE 184 R4 185 STOD	$Z_L \mathbf{q}_{21} + \mathbf{q}_{22}$ Compute $Z_L \mathbf{q}_{11} + \mathbf{q}_{12}$ INPUT: $\angle A$ A
934 935 936 937 938 949 941 942 943 944 945 946 947 949 959	RCL7 \$586 1/X X2Y CHS X2Y CHS \$105 \$4.BLE \$584 RCLB 1/X RCLI CHS \$589 \$R RCLB	Compute P ₂ /P ₁	### ##################################	$Z_L \mathbf{U}_{21} + \mathbf{U}_{22}$. Compute $Z_L \mathbf{U}_{11} + \mathbf{U}_{12}$ INPUT: $\angle A$ $\begin{vmatrix} A \\ \angle B \end{vmatrix}$
834 835 836 837 839 839 840 841 842 843 844 845 847 848 849 858 858	RCL7 GSB6 11/X X2Y CHS X2Y CHS GTO5 #LBLE GSB4 RCLB 11/X RCLI CHS GSB9 +R RCLA	Compute P ₂ /P ₁	898 RCL6 891 RCL5 892 RCL8 893 RCL7 894 GSB6 895 STOB 896 R4 897 STOI 898 RCL2 899 RCL1 180 RCL4 181 RCL3 182 **LBL6 183 STOE 184 R4 185 STOD 186 R4 187 RCL9 188 RCL9	$Z_L \mathbf{q}_{21} + \mathbf{q}_{22}$ Compute $Z_L \mathbf{q}_{11} + \mathbf{q}_{12}$ INPUT: $\angle A$ A
834 835 836 837 839 839 840 841 842 843 844 845 847 848 849 858 858	RCL7 GSB6 1/X X±Y CHS X±Y CHS GTO5 #LBLE GSB4 RCLB 1/X RCLI CHS GSB9 +R RCLA RCLA RCL9 +R	Compute P ₂ /P ₁	### ##################################	ZL\(\bar{\mathbf{Q}}_{21} + \bar{\mathbf{Q}}_{22}\) Compute ZL\(\bar{\mathbf{Q}}_{11} + \bar{\mathbf{Q}}_{12}\)
934 935 936 937 938 949 941 942 943 944 945 950 951 952	RCL7 GSB6 11/X X2Y CHS X2Y CHS GT05 #LBLE GSB4 RCLB 11/X RCLI CHS GSB9 +R RCLA RCL9 +R X2Y	Compute P ₂ /P ₁	898 RCL6 891 RCL5 892 RCL8 893 RCL7 894 GSB6 895 STOB 896 R4 897 STOI 898 RCL2 899 RCL1 180 RCL4 181 RCL3 182 #LBL6 183 STOE 184 R4 185 STOD 186 R4 187 RCL9 188 RCL4 189 GSB9	ZL\(\bar{\mathbf{Q}}_{21} + \bar{\mathbf{Q}}_{22}\) Compute ZL\(\bar{\mathbf{Q}}_{11} + \bar{\mathbf{Q}}_{12}\)
934 935 936 937 938 939 944 941 942 943 944 945 951 952 953	RCL7 GSB6 1/X X2Y CHS X2Y CHS GT05 #LBLE GSB4 RCLB 1/X CHS GSB9 +R RCLA RCLA RCL9 -R X2Y R1	Compute P ₂ /P ₁	999 RCL6 991 RCL5 992 RCL8 993 RCL7 994 GSB6 995 STOB 896 R4 997 STO1 998 RCL2 999 RCL1 180 RCL4 181 RCL3 182 ±18L6 183 STOE 184 R4 185 STOD 186 R4 187 RCL9 188 RCLA 189 GSB9 110 RCLD	$Z_L \mathbf{q}_{21} + \mathbf{q}_{22}$. Compute $Z_L \mathbf{q}_{11} + \mathbf{q}_{12}$ INPUT: $\angle A$ A A A B B B B B B B B
934 935 936 937 938 949 941 942 943 944 945 946 949 951 952 953 954	RCL7 SSB6 11/X XZY CHS XZY CHS GTOS 4LBLE GSB4 RCLB 1/X RCLI CHS GSB9 PR RCLA RCLA RCL9 AR XZY RJ FR XZY RJ FR FR RCLA RCLA RCLA RCLA RCLA RCLA RCLA RCL	Compute P ₂ /P ₁	898 RCL6 891 RCL5 892 RCL8 893 RCL7 894 GSB6 895 STOB 896 R4 897 STOI 898 RCL2 899 RCL1 180 RCL4 181 RCL3 182 **LBL6 183 STOE 184 R4 185 STOD 186 R4 187 RCL9 188 RCLA 189 GSB9 118 RCLA	ZL\(\bar{\mathbf{Q}}_{21} + \bar{\mathbf{Q}}_{22}\) Compute ZL\(\bar{\mathbf{Q}}_{11} + \bar{\mathbf{Q}}_{12}\)
934 935 936 937 938 939 944 941 942 943 944 945 951 952 953	RCL7 GSB6 1/X X2Y CHS X2Y CHS GT05 #LBLE GSB4 RCLB 1/X CHS GSB9 +R RCLA RCLA RCL9 -R X2Y R1	Compute P ₂ /P ₁	999 RCL6 991 RCL5 992 RCL8 993 RCL7 994 GSB6 995 STOB 896 R4 997 STO1 998 RCL2 999 RCL1 180 RCL4 181 RCL3 182 ±18L6 183 STOE 184 R4 185 STOD 186 R4 187 RCL9 188 RCLA 189 GSB9 110 RCLD	$Z_L \mathbf{q}_{21} + \mathbf{q}_{22}$. Compute $Z_L \mathbf{q}_{11} + \mathbf{q}_{12}$ INPUT: $\angle A$ A A A B B B B B B B B
934 935 936 937 938 949 941 942 943 944 945 946 949 951 952 953 954	RCL7 SSB6 11/X XZY CHS XZY CHS GTOS 4LBLE GSB4 RCLB 1/X RCLI CHS GSB9 PR RCLA RCLA RCL9 AR XZY RJ FR XZY RJ FR FR RCLA RCLA RCLA RCLA RCLA RCLA RCLA RCL		898 RCL6 891 RCL5 892 RCL8 893 RCL7 894 GSB6 895 STOB 896 R4 897 STOI 898 RCL2 899 RCL1 180 RCL4 181 RCL3 182 #LBL6 183 STOE 184 R4 185 STOD 186 R4 187 RCL9 188 RCL9 189 GSB9 110 RCLD 111 RCLD	ZL\(\mathbf{q}\)_{21} + \(\mathbf{q}\)_{22}. Compute \(Z_L\mathbf{q}\)_{11} + \(\mathbf{q}\)_{12} INPUT: \(\alpha\) A A \(\alpha\) B B OUTPUT: \(\alpha\)_{ZL} A + B
934 935 936 937 938 949 941 942 943 945 946 951 952 953 954 955	RCL7 SSB6 11/X XZY CHS XZY CHS GTOS 4LBLE GSB4 RCLB 1/X RCLI CHS GSB9 PR RCLA RCLA RCL9 AR XZY RJ FR XZY RJ FR FR RCLA RCLA RCLA RCLA RCLA RCLA RCLA RCL	REGI	899 RCL6 891 RCL5 892 RCL8 893 RCL7 894 GSB6 895 STOB 896 R4 897 STOI 898 RCL2 899 RCL1 160 RCL4 181 RCL3 182 LBL6 183 STOE 184 R4 185 STOD 186 R4 187 RCL9 188 RCL4 187 RCL9 189 RCL1 187 RCL9 188 RCL4 187 RCL9 188 RCL4 189 GSB9 111 RCLD 111 RCLE 112 GSB8	$Z_L \mathbf{U}_{21} + \mathbf{U}_{22}$. Compute $Z_L \mathbf{U}_{11} + \mathbf{U}_{12}$ INPUT: $\angle A$ $\begin{vmatrix} A & \\ B & \\ B \end{vmatrix}$ OUTPUT: $\angle Z_L A + B$ $\begin{vmatrix} Z_L A + B \end{vmatrix}$
934 935 936 937 938 949 941 942 943 944 945 946 949 951 952 953 954	RCL7 GSB6 1/X X2Y CHS X2Y CHS GT05 #LBLE GSB4 RCLB 1/X RCLI CHS GSB9 +R RCLA RCLA RCLA RCLA RCLA RCLA RCLA RCL	REGI	999 RCL6 991 RCL5 992 RCL8 993 RCL7 994 GSB6 995 STOB 896 RCL2 999 RCL1 100 RCL4 101 RCL3 102 #BL6 103 STOE 104 R4 105 STOD 106 RCL4 107 RCL9 109 RCL1 110 RCL3 110 RCL3 110 RCL3 110 RCL3 110 RCL3 110 RCL4 110 RCL3 110 RCL5 110 RCL5 110 RCL5 111 RCL6 111 RCL6 111 RCL6 111 RCL6 111 RCL6 112 GSB8	$Z_L \mathbf{U}_{21} + \mathbf{U}_{22}$. Compute $Z_L \mathbf{U}_{11} + \mathbf{U}_{12}$ INPUT: $\angle A$ $\begin{vmatrix} A & \\ B & \\ B \end{vmatrix}$ OUTPUT: $\angle Z_L A + B$ $\begin{vmatrix} Z_L A + B \end{vmatrix}$
934 935 936 937 938 949 941 942 943 944 945 947 959 951 953 954 955 955	RCL7 GSB6 1/X X2Y CHS ST05 #LBLE GSB4 RCLB 1/X RCLI CHS GSB9 +R RCLA RCLA RCL9 +R X2Y R1 ÷ ST0C	REGI:	999 RCL6 991 RCL5 992 RCL8 993 RCL7 994 GSB6 995 STOB 996 R4 997 STOI 998 RCL2 999 RCL1 180 RCL4 181 RCL3 182 LBL6 183 STOE 184 R4 185 STOD 186 R4 187 RCL9 188 RCLA 189 GSB9 110 RCLD 111 RCLD 111 RCLE 112 GSB8 STERS 5 17 18 18 19 11	$Z_L \mathbf{q}_{21} + \mathbf{q}_{22}.$ $Compute \ Z_L \mathbf{q}_{11} + \mathbf{q}_{12}$ $INPUT: \ \angle A \qquad A \qquad \angle B \qquad B $ $OUTPUT: \ \angle Z_L \ A + B \qquad Z_L \ A + B $ $ B \qquad B $
934 935 936 937 938 949 941 942 943 945 946 951 952 953 954 955	RCL7 GSB6 1/X X2Y CHS X2Y CHS GT05 #LBLE GSB4 RCLB 1/X RCLI CHS GSB9 +R RCLA RCLA RCLA RCLA RCLA RCLA RCLA RCL	REGI	999 RCL6 991 RCL5 992 RCL8 993 RCL7 994 GSB6 995 STOB 896 RCL2 999 RCL1 100 RCL4 101 RCL3 102 #BL6 103 STOE 104 R4 105 STOD 106 RCL4 107 RCL9 109 RCL1 110 RCL3 110 RCL3 110 RCL3 110 RCL3 110 RCL3 110 RCL4 110 RCL3 110 RCL5 110 RCL5 110 RCL5 111 RCL6 111 RCL6 111 RCL6 111 RCL6 111 RCL6 112 GSB8	$Z_L \mathbf{U}_{21} + \mathbf{U}_{22}$. Compute $Z_L \mathbf{U}_{11} + \mathbf{U}_{12}$ INPUT: $\angle A$ $\begin{vmatrix} A & \\ B & \\ B \end{vmatrix}$ OUTPUT: $\angle Z_L A + B$ $\begin{vmatrix} Z_L A + B \end{vmatrix}$
934 935 936 937 938 949 941 942 943 944 945 947 959 951 953 954 955 955	RCL7 GSB6 1/X X2Y CHS ST05 #LBLE GSB4 RCLB 1/X RCLI CHS GSB9 +R RCLA RCLA RCL9 +R X2Y R1 ÷ ST0C	REGI:	999 RCL6 991 RCL5 992 RCL8 993 RCL7 994 GSB6 995 STOB 996 R4 997 STOI 998 RCL2 999 RCL1 180 RCL4 181 RCL3 182 LBL6 183 STOE 184 R4 185 STOD 186 R4 187 RCL9 188 RCLA 189 GSB9 110 RCLD 111 RCLD 111 RCLE 112 GSB8 STERS 5 17 18 18 19 11	$Z_L \mathbf{q}_{21} + \mathbf{q}_{22}.$ $Compute \ Z_L \mathbf{q}_{11} + \mathbf{q}_{12}$ $INPUT: \ \angle A \qquad A \qquad \angle B \qquad B $ $OUTPUT: \ \angle Z_L \ A + B \qquad Z_L \ A + B $ $ B \qquad B $
834 835 836 837 838 839 840 841 842 843 844 845 845 848 849 851 852 853 853 854	RCL7 \$SB6 11/X X2Y CHS X2Y CHS \$T05 \$LBLE \$SSB4 RCLB 1/X RCLI CHS \$SB9 +R RCLA RCL9 +R X2Y RJ \$100 1	REGI:	898 RCL6 891 RCL5 892 RCL8 893 RCL7 894 GSB6 895 STOB 896 R4 897 STOI 899 RCL2 899 RCL1 180 RCL4 181 RCL3 182 ★LBL6 183 STOE 184 R4 185 STOD 186 R4 187 RCL9 188 RCLA 189 GSB9 110 RCLB 111 RCLE 112 GSB8 STERS 56 57 56 57 56 57 56 57 57 56 57 58 56 57 58 58 58 58 58 58 58 58	$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$
934 935 936 937 938 949 941 942 943 944 945 947 959 951 953 954 955 955	RCL7 GSB6 1/X X2Y CHS ST05 #LBLE GSB4 RCLB 1/X RCLI CHS GSB9 +R RCLA RCLA RCL9 +R X2Y R1 ÷ ST0C	REGI:	999 RCL6 991 RCL5 992 RCL8 993 RCL7 994 GSB6 995 STOB 996 R4 997 STOI 998 RCL2 999 RCL1 180 RCL4 181 RCL3 182 LBL6 183 STOE 184 R4 185 STOD 186 R4 187 RCL9 188 RCLA 189 GSB9 110 RCLD 111 RCLD 111 RCLE 112 GSB8 STERS 5 17 18 18 19 11	$Z_L \mathbf{q}_{21} + \mathbf{q}_{22}.$ $Compute \ Z_L \mathbf{q}_{11} + \mathbf{q}_{12}$ $INPUT: \ \angle A \qquad A \qquad \angle B \qquad B $ $OUTPUT: \ \angle Z_L \ A + B \qquad Z_L \ A + B $ $ B \qquad B $

113 RTN		 ute I ₂ /V ₁					
.114 *LBLc 115 RCL2	Compo	ite 1 ₂ / V ₁					
116 RCL1							
117 RCL4	i						
118 RCL3							
119 GSB€							
120 1/X							
121 X#Y							
122 CHS 123 X≇Y	l		1				
123 X≢Y 124 CHS							
125 GT05							
126 #LBLd	Compu	ite V ₂ /I ₁	1				
127 RCL6							
128 RCL5							
129 RCL8							
130 RCL7 131 GSB6	l						
131 GSB6 132 RCLA							
133 RCL9	ı						
134 Rt	- 1						
135 CHS	ı						
13€ R1	1						
137 1/X							
138 XZY 139 GSB9	1						
140 GT05	- 1						
141 #LBL8	Subro	tine to add com	nlev				
142 →R	numbe		piex				
143 RJ							
144 RJ	- 1						
145 →R	- 1						
146 X2Y 147 R4	1						
148 +	1						
149 R4							
150 +						l	
151 R1							
152 →P 153 RTN							
154 #LBL9	1						
155 R4		itine to multiply ex numbers.					
156 ×	10000	A Hambers.					
157 R4							
158 + 159 Rt							
159 KT 160 RTN							
161 R/S							
	- 1						
	- 1						
	- 1						
		DEL C		FLAGS		CET CTATUS	
A Z _L B →Z _{in}	Ic LAI	BELS	E _ D /D			SET STATUS	
	~ ~ \/ /\/						
a b	$C \rightarrow V_2/V_1$ $C \rightarrow I_2/V_1$	$D \rightarrow I_2/I_1$ $D \rightarrow I_2/I_1$	E → P ₂ /P ₁	⁰ PRINT	ON OFF	TRIG DEG ☑	DISP FIX 🗆

		LAE	BELS		FLAGS		SET STATUS	
A ZL	^B →Z _{in}	$^{C} \rightarrow V_{2}/V_{1}$	$D \rightarrow I_2/I_1$	$E \rightarrow P_2/P_1$	O PRINT	FLAGS	TRIG	DISP
а	b	C → I ₂ /V ₁	$d \rightarrow V_2/I_1$	е	1	ON OFF	DEG 🛭	FIX 🗆
O Printy & x	1	2	3	⁴ Z ų ₂₁ + ų ₂₂	2	1 🗆 🕱	GRAD □ RAD □	SCI □ ENG ko
⁵ Display	⁶ Z _L A + B	7	⁸ CADD	9 CMULT	3	3 🗆 🕱	TIAD G	n 3

Reactive L-Network Impedance Matching

			T 053			
001	*LBLA	l	057 *LB			change Z_S and Z_L .
992	STO1	Store R _L		B2	Cor	mpute X _{1 (+)} .
993	R↓			B1		mpute X ₂ .
004	STO2	Store X _L		B5		
005	R/S			BE		
906	*LBLE	Store R _S	062 GS	B 5		
907	ST03	, ,	063	+	Sav	e X ₂ in LSTx.
908	R.J.		964 GS	B 2		change Z _S and Z _L .
009	ST04	Store X _S	065 LS	TX		cover X ₂ .
610	R/S		966 F	TN		
011	#LBL1	Subroutine to compute	967 #LE	l d	Ev	change Z _S and Z _L .
012	RCL2			B2		
013	XS	$X_{1(+)}$ and $X_{1(-)}$.		B1	0	mpute X ₁₍₋₎ .
014	RCL1			15		
					l	
015	Χs			B 5		
016	+			BE	Cor	mpute X ₂
017	RCL3	i		B5	- 1	
018	×		074	+	Sav	e X ₂ in LSTx.
019	RCL1			B 2		change Z _S and Z _L .
020	RCL3		076 LS	TX		cover X ₂ .
021	-		977 F	TN		
922	÷		978 *LE	l F	e	proutine to compute
023	LSTX			07		
024	1/8			L2	X ₂	
025	RCL3		981	+	ł	
026	X			L3	1	
827	RCL2				- 1	
828	X		083	× _	i	
029	χz			L7	i	
				L4	ı	
939	LSTX		986	+	- 1	
031	R↓			L1	ı	
032	+		988	X	ĺ	
033	1%		089	-	l	
034	RŤ			L1	1	
035	X≠Y		091	÷	1	
036	-			?TN	1	
037	ST05		893 *LI	BL2		proutine to exchange
938	LSTX		094 RI	L1		
039	ENT†		095 RI	L3	∠s	and Z _L .
949	+		896 S	01		
041	+			₹₹Y		
842	ST06	1		103	ı	
843	RTH			L2	ı	
844	*LBLC			L4	- 1	
045	GSB1	Compute X ₁₍₊₎		102	ı	
846	GSB5			102 { 2 Y	l	
047	ESBE	Compute X ₂		T04	ı	
048	GSB5	1		RTN	l	
049	RTN			BL5	פום	SPLAY ROUTINE
950	≉LBL c	Compute X ₁₍₋₎		9?		flag 0
051	ESB1			RTX		EN PRINT
95 2	RCL5			F 0 ?	1	
953	GSB5			RTN	l EL	SE
054	GSBE	Compute X ₂	110	R/S		DISPLAY.
95 5	GSB5		111	RTN	ı	
95€	RTN		112	R/S	ı	
		REC	SISTERS			
0	1	2 3 4	5 6	7	8	9
	RL	X _L R _S X _S		1(+)	X ₁	
S0	S1	S2 S3 S4	S5 S6	S	7 S8	S9
<u> </u>	Щ,		D		1	
^		С	٢	E		ľ

					l
					l
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	LABELS	FLAGS		SET STATUS	
IA ID IC	LABELS				
A XLTRL B XSTRS C T	LABELS D -O F	0 PRINT	FLAGS	TRIG	DISP
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	D D E		FLAGS	TRIG	
° .2	de	0 PRINT	FLAGS	TRIG	
° .2	de	O PRINT			DISP FIX SCI □ ENG □ n 2

Class A Transistor Amplifier Bias Optimization

001	#LBLR				057	STOE				
862	RCL9	1	Transfer V _{BEn}	nax to	€ 58	1				
883	₽₽S		secondary regi		659	RCL1				
004	ST09				960	Χs				
805	₽₽S	1			0€1	-				
1 00€	RCL4	l l			962	2				
007	2	1			063	÷				
		1								
668	5	ļ			064	RCL I				
809	-	1	Compute θ_{JA}		965	×				
010	RCL5	1			966	RCL5		Cor	npute T	min
011					867	X				
	-									
8:2	ST 05				868	RCLØ		ŀ		
e13	RCLO				9 €9	×				
814	Χź	1			878	RCL3				
015	ÿ	1				+				
		1.	O		071					
816	RCL 4	- 1	Compute R _{L1}		872	esb3				
817	RCL2				673	CHS				
018	-	I			874	1		1		
		i i				•		C	npute V	
0 19	4	1			e75	RCL1		Cor	npute v	BEN
020		1			076	-		1		
821	4	1			e77	GSB4				
022	x	l			6 78	P 29		1		
		1								
0 23	÷				0 79	RCL9		ł		
624 625	STOC	l l			e 8e	+				
825		i			681	P#8				
626	•	1.	Compute R _{E1}					1		
	*	I '	compate nE1		882	ST09		١		
€27	×				683	RCLE		115	$v_{BEX} >$	VBEN
028	STOD	1.			084	82.45		TH	EN redu	ce R _E to 0
629	#LBL0	11	Begin iterative	loop.	685	GT02			and incr	ement R _I
636	RCLO					6102		ELS		
	KLLE	- 1			68€					e a new value
631 632	.2				9 87	RCLI				e a new value
	÷				389	÷		1	for R _E .	
633	ENT↑	1			889	RCL1				
034	ENT†	1						1		
835	RCLC	1			696	÷				
		1			091	RCLD				
636	RCLD	1			692	XTY		1		
e 37	+	1.	Compute I _{ca}		893	STOD		1		
638	÷	1	Compate 1cq					1		
639	STOI				094	ZCH		1		
					695			1		
848	RCL5				89€	5		I IF &	$\Delta R_E \ge .$	5%
841	×				097	XZY?		Тн	EN repe	at loon
842	×	- I -	Compute T _{max}		899	STOR			flag 1	op
043	RCL2	Ι.	ma:	•						
					69 9	F1?				h problem
044	+				100	GT01			SE repea	
045	RCL4				101	SF1		1 0	once mo	re to print.
84€	XZY		IET ST		102	STOR				
847	8272	١.	IF T _{max} > T _J	nax				1		
		1.	THEN increase	H L	103	#LBL1		1		
848	GT01				104	CF1		1		
049	ESB3	- 1	ELSE comput	VREY.	185	R/S		Sto	n to acc	ept h _{FE} 's
656	CHS	1	put	DEV.	106	STOP		1 5,0	p to acc	Christs a
	RCL1							1		
051 052		l			107	XZY			re hFEm	
	. 1				108	STDA		Sto	re h _{FEm}	iax
6 53	+				189	RCL1		1		
85 4	GSB4	ļ			liie	2		1		
855	RCLE	J			111	×		l		
05€	+	1						l		
636					112	RCLI				
				REGIS	STERS					
° v _{cc}	¹ ∆I _{cq}	² T _{Amax} ,R _B	3 T _{Amin} ,V _{BB}	4 T _{Jmax}	$^{5}P_{D}, \theta_{JA}$	6 I ₁	7 ∆V _{BE}	8 V _B		9 V _{BEN}
								V B	Emin	
S0	S1	S2	S3	S4	S5	S6	S7	S8		S9
										V _{BE max}
	В		c		D		E		lı .	
h _{FEmax}	ا	hFEmin	R _{Ln}		R _{En}		V _{BEX}		Ico	

Used	¹ Used	² Used		³ Used	4 Us	ed	Used 2	0 X 1 X 2 X	DEG ₺ GRAD □ RAD □	FIX □ SCI □ ENG ☑
`→Ţ I _c	^B Used	c		d	e		1 Head	FLAGS ON OFF	TRIG	DISP
		Ic		ELS D	E		FLAGS		SET STATUS	
167 168	÷ RCLĐ									
16€	PRST		PRINT	R ₁ , R ₂ , R _L , R	E	221	K/S			
	RCLD RCLD					22 0 221	STOØ R∕S			
163	÷ RCLC		-		-	219	STOC			
162	RCL3					217 218	RCLC		R _{Ln+1}	
	LSTX		Compu	te R ₂		21€	1			C.,
159	x					214 215	1		R _{Ln+1} ←R	In x 1.1
	RCL2 RCL0					213				
15€	X DOLO		-		-	212	STOD			
	RCL2					21 0 211	≉LBL2 Ø		UE _ 0	
153 154	X ≇ Υ ÷					289	RTH		 R _E ←0	
	RCLE		Compu	te R ₁		208	+			
151	ST03		_		-	206 207	X X			
149 150	RCL9					2 9 5 2 9 6	LOG RCL7		1	
148	X BCI 0					204	÷			
147	-					202 203	RCLE		"""	ic.
145 146	RCL1					2 0 1 2 0 2	F1? PRTX		IF flag 1 THEN PRI	NT I.
144	x		Compu	te V _{BB}		200	×		l	
	RCLI					198			1	
141 142	RCLD +					197 1 9 8				
14€	÷					196				
	RCLE					195				
137 138	÷ 5702		_		_	193 194				
13€	RCLI					192				
135	÷					191			0.0022 (x	- 25)
133 134	<i>x</i>					189 196			Compute	
	RCLB					188			Compute	
131	+					187	2			
129 1 30	1 RCL1					185 186			THEN PRI	NT T.
128	x					184			IF flag 1	
127	RCLA					183	RTH			
125 126	RCL1					181				
124	PC 1					186 181				
123	x					179	1			
122	RCLA		Compu	te R _B		178				
12 0 121	RCLE					176 177				
119	-					175				
118	RCL9					174	RCLE			•
11€ 117	RCLE +					17: 17:			Compute A	A _D
:15	X DC/ F					171				
	RCLD				- 1	170			1	

Transistor Amplifier Performance

198	*LBLA		T			857	RCL3					
882	2		1			85 8	RCL4					
			1									
883	×		l			85 9	ESB9		1			
804	2		ı			968	RCL2		l			
005	1		Com	oute stor	age location.	861	RCL1					
886	-		l			962	CSB8					
997	STOI		ı			863	STOR					
300	R↓		ı									
			ı			964	XZY					
009	STO:		Store	hii		865	STOI					
818	ISZI		l	,		866	F1?			IF t	flag 1	
011	R↓		ı			867	CSB5			TH	EN PRI	NT or
812	STO:		Store	A							PLAY.	
613	RTN		31016	v _{ij}		968	XZY					
						869	F1?				flag 1	
814	*LBLB		l			878	ESB5				EN PRI	NT or
815	ST07		Store	R ₁		871	F1?			DIS	PLAY.	
81€	X≆Y		ı	-		672	SPC					
817	ST08		Store	Α.					i			
			0.016	V.L		073	RTH					
818	RTN					874	*LBLD		l	Cor	npute A	vs
019	*LBLb		ı			875	CF1		j			
626	ST05		Store	Re		876	GSBe			Cor	noute Z	in without
821	XZY								i	pri	iting.	W)
822	STO6		Store	Δ.		877	SF1			, PIII	iting.	
			Store	us.		9 78	RCL 6					
023	RTH					9 79	RCL5		1			
824	*LBLc		Comp	ute A _i		880	CSB8					
825	GSB7		l			881	1/X		l			
826	X#Y					082	XZY		1			
			l						1			
827	CSB5					883	CHS					
828	XZY		l			8 84	XZY					
829	CSB5		l			85	RCL9					
636	SPC		l			886	RCLA		1			
	RTH		ı									
031						887	£5 8 9					
832	*LBLC		Comp	ute A _v		888	RCL7					
03 3	CF1		1			889	RCL8					
834	CSBe		Comp	ute Z _{in} v	without	898	CSB9		1			
835	SF1		printi	na. "'		891	XZY					
936	1/X								1			
	1/4		l			092	esb5					
837	XZY		l			893	XZY					
838	CHS					894	CSB5					
039	XZY					895	SPC		1			
848	RCL7											
841	RCL8					896	RTH			-		
			ŀ			897	*LBLE		I	Con	npute Z	out
042	esb9		l			29 8	RCL2		ı			
843	RCL9		ı			89 9	RCL1		ı			
844	RCLA		l			180	RCL6		ı			
845	GSB9		l									
846	XZY		l			101	RCL5		I			
			l			1 0 2 1 0 3	CSB8		ı			
847	ese5		l				1/X		l			
848	X≇Y		I			184	XZY		l			
849	CSB5		l			165	CHS		I			
858	SPC		l			186	X≢Y		1			
	RTH		l						ł			
95 1	*LBLe		Com	7		107	RCLB					
			Comp	ute Z _{in}		108	RCLC		l			
95 3	CSB7		I			109	CSB9		1			
85 4	RCL7		l			110	RCL3		ı			
85 5	RCL8		l			111	RCL4		1			
856	ESB9		l			112	CSB9					
100	3003				DEC.	TERS	6303					
0	1.	To	To .		HEGIS		le .		T-	To		To
10	h ₁₁ = h _i	θ_{11}	o h₁:	2 = h _r	θ ₁₂	⁵ R _S	θ_{S}		7 RL	8 6	L	9 IAil
Z _{in}	1 1111 - 11									1 '	_	
			62		C4	C E	ce		67	tco.		co
S0	S1	S2	S3		S4	S5	S6		S7	S8		S9
	S1	S2	S3		S4		S6	_	S7	S8		S9
		S2	S3	С _{Ө2}		D h ₂₂ = h ₀	S6	E	S7 θ ₂₂	S8	ı	S9

113	CHS					1€	9 R ‡		Subroutine	to multiply
	RCLE	- 1				17			complex n	
	RCLD					17			1	
	CSB8 1/X					17	2 +		l	
117 118	12A X ⊋ Y					17				
119	CHS					17				
	GSB5					17	5 K/S		1	
121	X#Y									
	CSB5					l				
123 124	SPC RTN	- 1				l			1	
	LBL5		IF flag	•		l				
126	FØ?			PRINT		ł				
127	PRTX		IF flag	0		l				
128	F8?			RETURN		l				
129	RTH		ELSE	DISPLAY.		1				
130 131	R/S RTN									
	LBL7		Subrou	tine to compu	te A _i .	l				
	RCLE					l				
134	RCLD								1	
	RCL7					1				
	RCL8					l				
137 138	GSB9					1				
	ENT†					1				
140	1	- 1								
	ESB8	- 1								
142 143	1/X X≇Y									
144	CHS									
145	XZY								l	
	RCLB								l	
147	CHS								l	
	RCLC								l	1
	ST09	- 1							l	
151	X#Y									
152	STDA								ŀ	I
153	XZ	- 1								
154	RTH		Cubra						l	1
155 # 156	LBLS →P.		numbe	tine to add cor	пріех				l	1
157	R↓								1	
158	R4									Ì
159	→R XZY									l
160 161	RJ									
162	+								1	
163 164	R4								l	- 1
	† D+									İ
165 166	R† →F									
167	RTH								1	
	LBL9									
	-		LAE	ELS			FLAGS		SET STATUS	
Aθ _{ij} †h _{ij} †ij	B $\theta_{L} \uparrow R_{L}$	C →Av		D → A _{vs}	E →	Z _{out}	⁰ PRINT	FLAGS	TRIG	DISP
a	b θ _S †R _S	c →A!		d	_	Z _{in}	1 NO PRINT	ON OFF	DEG 😡	FIX 🗆
0	1	2		3	4		2	1 😡 🗆	GRAD □	SCI 🗆
5 DISPLAY	6	⁷ A _i		⁸ CADD	9 C	MULT	3	2 🗆 🖸	RAD 🗆	ENG 🗷
DIGITAL	L	L ~i		LONDO	1 -		L	3 🗆 😿		n3

Transistor Configuration Conversion

001 802	*LBLA 2			8 57	RCLE		
		- 1	Compute register to be	₽5 8	RCLD		$y_{12}' = -(y_{12} + y_{22})$
963	X		Compute register to be	8 59	esbe		712 (712 - 7227
e 94	2		used.	860	CHS		
005	1			861	ST03		
00€	-			862	X#Y		
887	STOI			863	ST04		
888	P.J						
ee 9	STO:	- 1		864	XZY		
		- 1	Store h _{ij}	865	RCLC		
0 10	ISZI			966	RCLE		
81 1	R↓	1		8€7	ESB8		
012	STO:		Store θ_{ii}	968	RCLE		
013	RTN						
014	*LBLC		00.00	069	RCLD		$y_{11}' = -y_{22} + (y_{21}' + y_{12}')$
			CC→CB	878	ESB 8		+ y ₁₁
015	esb0		Compute a new y-matrix.	e71	CHS		
01€	*LBL3			872	RCL2		$= y_{11} + y_{12} + y_{21} + y_{33}$
617	RCL1		Routine to transform	873	RCL1		
€18	RCLD	1					
		- 1	a ₂₂ a ₂₁	674	€SB€		
019	ST01		1	875	ST01		
828	R↓		a ₁₂ a ₁₁	87€	R↓		
821	STOD	1	into	877	ST02		
822	RCL3	- 1		878	RTH		
623	RCLE	1	[a ₁₁ a ₁₂]				05.00
			1 1	879	#LBL d		CE→CC
024	ST03		a ₂₁ a ₂₂	686	*LBLD		CC→CE
025	R↓	í	and then into	881	ESB0		Compute new y-matrix
82€	STOE	- 1		882	GSB7		Transform [y] to [h].
e 27	RCL2	1	1 1 -a ₁₂				mansionin (y) to (ii).
828	RCLE		a ₁₁ a ₂₁ det a	883	RTN		
			[884	*LBLc		CB→CC
82 9	STO2			885	ESB0		Compute new y-matrix
838	R↓			886	6703		Transform
8 31	STOE				*LBL0		
8 32	RCL4	1		887			
				988	SSB7		Transform [h] to [y] '
633	RCLC	- 1		889	RCL2		
€34	ST04	1		696	RCL1		
935	R↓	1		891	RCL4		
03€	STOC						
03 7	GSB?			892	RCL3		$y_{12}' = -(y_{11} + y_{12})$
				893	esb8		
0 38	RTH			894	CHS		
e 39	*LBL&		CB→CE	095	ST03		
848	*LBLB	- 1	CE→CB	l €9€	RĮ		
841	ESB8	- 1		897	ST04		
	GSB?	l	Compute a new y-matrix.				
842		I	Transform [y] to [h].	898	RCL2		
043	RTH	ı		899	RCL1		
844	*LBL0	- 1	Transform [h] to [y] '	100	RCLC		
645	ESB7	- 1	manaronni [n] to [y]	181	RCLB		
	RCLC	- 1					
84€		- 1		182	esb8		$y_{21}' = -(y_{11} + y_{21})$
847	RCLE	- 1		183	CHS		
		1		184	STOE		
84 8	RCLE			105	X ≠ Y		
		- 1					
849	RCLD		$y_{21}' = -(y_{21} + y_{22})$				
849 858	RCLD GSB8		$y_{21} = -(y_{21} + y_{22})$	10€	STOC		
849 858 851	RCLD GSB8 CHS		$y_{21} = -(y_{21} + y_{22})$	196 197	STOC X≇Y		
049 050 051 052	RCLD GSB8 CHS STOB		$y_{21} = -(y_{21} + y_{22})$	106 107 108	STOC XZY RCL4		
849 858 851	RCLD GSB8 CHS		$y_{21} = -(y_{21} + y_{22})$	196 197	STOC X≇Y		
049 050 051 052 053	RCLD GSB8 CHS STOB RJ		$y_{21} = -(y_{21} + y_{22})$	106 107 108 109	STOC XZY RCL4 RCL3		V22' = V11 + V12 + V2. + V
849 858 851 852 853 854	RCLD GSB8 CHS STOB R1 STOC		y ₂₁ = -(y ₂₁ + y ₂₂)	106 107 108 109 110	STOC XZY RCL4 RCL3 GSB8		y ₂₂ ' = y ₁₁ +y ₁₂ +y ₂₁ +y
849 858 851 852 853 854 855	RCLD GSB8 CHS STOB R1 STOC RCL4		Y ₂₁ = -(Y ₂₁ + Y ₂₂)	186 187 188 189 118	STOC XZY RCL4 RCL3 GSB8 RCL2		y ₂₂ ' = y ₁₁ +y ₁₂ +y ₂₁ +
849 858 851 852 853 854	RCLD GSB8 CHS STOB R1 STOC			106 107 108 109 110 111	STOC XZY RCL4 RCL3 GSB8		y ₂₂ ' = y ₁₁ +y ₁₂ +y ₂₁ +
849 858 851 852 853 854 855	RCLD GSB8 CHS STOB STOC RCL4 RCL3		REG	106 107 108 109 110 111 112 STERS	STOC X2Y RCL4 RCL3 GSB8 RCL2 RCL1		
849 858 851 852 853 854 855	RCLD GSBB CHS STOB RJ STOC RCL4 RCL3	² θ ₁₁	REG	106 107 108 109 110 111	STOC XZY RCL4 RCL3 GSB8 RCL2		y ₂₂ ' = y ₁₁ + y ₁₂ + y ₂₁ + y ₂₁
849 858 851 852 853 854 855	RCLD GSBB CHS STOB RJ STOC RCL4 RCL3	² θ ₁₁ S2	REG	106 107 108 109 110 111 112 STERS	STOC X2Y RCL4 RCL3 GSB8 RCL2 RCL1	7 ΔΔ S7	y ₂₂ ' = y ₁₁ + y ₁₂ + y ₂₁ + y 8 9 S8 S9
849 858 851 852 853 854 855	RCLD GSBB CHS STOB RJ STOC RCL4 RCL3	011	REG	106 107 108 109 110 111 112 STERS	STOC X2Y RCL4 RCL3 GSB8 RCL2 RCL1		8 9

113 GSB8 169 ST00 170 R1 171 ST0E 171 ST0E 172 RTN 173 4LBLS Subroutine to add complex numbers. Stop								
115 RCLE								
11								
117 ESBS	115	RCLE	- 1				1	
119 ST00	11€	RCLD	- 1					
1:15 STOD		SBS	1		173 #LBL9		Subroutine	e to add
119							complex n	umbers.
128 STOE 121 RTW 122 aLBL7 Subroutine to convert 176 R4 R17 R12 ALBL7 RC12 ALBL7 ALBC7 ALBT7			- 1					
121 RTN			1				1	
122							1	
1223 RCL2 2			ء ا	Subrouting to convert			1	
124 RCL1			١٩	r -				
125 RCLE			- 1	a ₁₁ a ₁₂				
126 RCLE			- 1	a21 a22			1	
127 SSB9 128 1				1			1	
128 ST06 129 R4 139 ST07 131 RCL4 132 RCL3 132 RCLB 133 RCLB 133 RCLC 133 RCLC 134 RCLC 135 CSB9 136 CHS 137 RCL7 138 RCL6 139 CSB8 139 R4 137 RCL7 138 RCL6 139 CSB8 140 ST06 141 R1 141 R1 142 ST07 143 RCL2 144 CHS 145 ST02 144 CHS 146 RCL1 147 1/X 148 ST01 149 RCL3 140 RCL3 140 RCL3 150 RCL4 151 RCL4 152 CSB9 153 RCL4 154 RCL1 155 RCL4 155 RCL4 156 RCL2 157 RCL7 158 RCL6 159 RCL2 150 RCL2 150 RCL2 150 RCL2 151 RCL4 152 RCL3 155 RCL4 155 RCL4 155 RCL4 155 RCL4 156 RCL2 157 RCL7 158 RCL6 159 RCL2 150 RCL2 157 RCL7 158 RCL6 159 RCL2 150 RCL2 150 RCL2 151 RCL4 152 RCL3 155 RCL4 155 RCL4 155 RCL4 156 RCL2 157 RCL1 158 RCL6 159 RCL2 157 RCL1 158 RCL6 157 RCL1 158 RCL6 157 RCL7 158 RCL6 159 RCLC 150			1.				1	
129 F 1			l "					
129				1 1 -a ₁₂				
138 SIU								
132 RCL3 188 X 189 R4 190 H 137 KCLC 190 H 191 R7 135 KCSB9 191 R7 136 KCL6 192 HR 197 KCL7 138 KCL6 193 KCL6 195 KCL2 195 KCL6 195 KCL2 197 KCL2 197 KCL2 197 KCL2 197 KCSS5 196 KCL2 197 KCSS5 196 KCL2 197 KCSS5 196 KCL2 197 KCSS5 197 KCL2 199 KCL2 199 KCL1 199 KCL2 199 199 KCL2 199 KCL			- 1	a11 a21 det a				
1327 RCLB 189 R4 199 H2 191 R7 191 R7 192 H2 H2 192 H2 H2 H2 H2 H2 H2 H2			- 1				complex n	umbers.
1327 RCLB 189 R4 199 H2 191 R7 191 R7 192 H2 H2 192 H2 H2 H2 H2 H2 H2 H2	132	RCL3	- 1				1	
134			- 1				1	
135 6889 191 Rt 136 CHS 137 RCL7 Compute det a 193 +P 138 RCL6 194 RTH RCL2 195 48 195 48 RCL2 197 6858 195 48 RCL2 197 6858 195 48 RCL2 197 6858 195 68 RCL2 197 6858 195 RCL4 195 RCL4 195 RCL4 195 RCL5		RCLC	- 1		190 +		I	
136			- 1				1	
137 RCL7 138 RCL6 195 4F 194 RTM 139 GSB8 195 4F 195 4F RTM 139 GSB8 196 RCL2 197 GSB5 142 ST07 198 RCL1 199 GSB5 142 ST07 198 RCL1 199 GSB5 144 CMS 199 GSB5 146 RCL4 145 ST02 146 RCL1 120 RCL3 146 RCL1 147 17% 280 GSB5 148 ST01 149 RCL3 280 RCL6 148 ST01 149 RCL3 280 RCL6 150 RCL4 160 RCL4 160 RCL6 151 RCL4 160 RCL6 151 RCL4 160 RCL6 152 GSB9 161 ST08 161 ST08 161 ST08 161 ST08 161 ST08 161 ST08 162 RL 163 RCL2 165 RCL2 165 RCL2 165 RCL2 166 RCL6 167 RCL7 168 GSB9 161 ST08 161 ST08 161 ST08 162 RCL2 165 RCL2 165 RCL2 165 RCL2 166 RCL6 167 RCL7 168 GSB9 161 ST08 161 ST08 161 ST08 162 RCL6 165 RCL2 165 RCL2 165 RCL2 165 RCL2 165 RCL2 165 RCL2 166 RCL6 167 RCL7 168 GSB9 161 ST08 161 ST08 161 ST08 162 RCL5 164 RCL2 165 RCL1 166 RCL6 167 RCL7 168 GSB9 169 RCL6 169 RCL6 160 RC			J				1	
138			l c	Compute det a			1	
139 CSB8 196 RLE 196 RLE 197 CSB5 196 RCL1 197 CSB5 198 RCL1 197 CSB5 198 RCL1 199 CSB5 199 199 CSB5 199 199 CSB5 199 199 CSB5 199 199 CSB5 199			١٣	ompate det a			l	
140 ST06 197 SSB5 198 RCL1 197 SSB5 142 ST07 198 RCL1 199 SSB5 144 CHS 208 RCL4 145 ST02 146 RCL1 147 17% 208 CSB5 208 RCL3 208 RCL3 208 RCL3 208 RCL4 208 RCL4 208 RCL5 208			1				Print [h]	. – – – – –
141							Finit (iii)	
142 ST07 198 RCL1 199 GSB5 144 CHS 145 ST02 146 RCL1 120 GSB5 147 178 178 148 ST01 149 RCL3 200 RCL4 200 RCL4 200 RCL5							ĺ	
143 RCL2 199 CSB5 200 RCL4 145 ST02 146 RCL1 128 CSB5 200 RCL3 201 CSB5 202 RCL3 202 RCL5 202 202 RCL5			- 1					
144			-				ı	
145 ST02 146 RCL1 147 178 148 ST01 149 RCL3 282 RCL3 282 RCL3 282 RCL2 282 RCL6 285 286 RCL6 285 286 RCL6 287 CSB5 286 RCL6 287 CSB5 286 RCL6 287 CSB5 288 RCL6 287 RCL1 287 RCL1 287 RCL2 287 RCL1 287 RCL1 287 RCL6 RCL			- 1				1	
147 17 17 18 18 18 19 19 19 19 19				1			1	
147 17 17 18 18 18 19 19 19 19 19			a	11 ←			1	
148 ST01 149 RCL3 150 CHS 151 RCL4 152 CSB9 153 ST03 154 R↓ 155 ST04 156 RCL2 157 RCL1 157 RCL1 158 RCLD 158 RCLD 159 RCLC 157 RCL1 158 RCLB 159 RCLC 160 CSB9 161 ST0B 161 ST0B 162 R1 162 R1 163 ST0C 164 RCL2 165 RCL2 165 RCL2 165 RCL2 165 RCL2 165 RCL2 166 RCL6 167 RCL7 168 CSB9 LABELS L	14€	RCL1	- 1	a11			1	
149 RCL3 150 CHS 151 RCL4 152 CSB9 153 ST03 154 RJ 155 ST04 155 ST04 156 RCL2 157 RCL1 158 RCLB 157 RCL1 158 RCLB 159 RCLC 157 RCL1 158 RCLB 159 RCLC 159 RCLC 151 RCLB 150 RCLC 151 RCLD 151 RCLD 152 RCLD 155 RCLB 155 RCLB 156 RCLB 157 RCL1 158 RCLB 159 RCLC 159 RCLC 159 RCLC 150 RCLC 150 RCLC 151 RTN 152 RCLB 153 RCLC 154 RCC 155 RCLC 155 RCLC 156 RCLC 157 RCL1 166 RCLC 167 RCL7 168 SSB9 161 ST0B 162 RJ 163 ST0C 164 RCL2 165 RCL1 166 RCL6 167 RCL7 168 SSB9 LABELS LABELS LABELS FLAGS SET STATUS A θ _{ij} th _{ij} tij			- 1				I	
158			1 –		204 RCLC		1	
151 RCL4 287 SSB5 288 RCL5 288 RCL5 218			l l		205 GSB5		1	
152 GSB9 153 ST03 154 R↓ 155 ST04 156 RCL2 157 RCL1 158 RCLB 159 RCLB 161 ST08 161 ST08 162 R↓ 163 ST0C 164 RCL2 165 RCL1 166 RCL2 167 RCL1 166 RCL2 167 RCL1 167 RCL1 168 RCL8 169 RCLC 160 RCL2 170 RCL1 180 RCLC 181 RCLC 181 RCLC 181 RCC 181 RC					20€ RCLB		ì	
152							İ	
154 Rt 219 RCLD 155 ST04 211 st.BL5 212 F8° 156 RCL2 213 PRIX 214 F8° 215 RCLD 215 RTN 216 Rt Rt Rt Rt Rt Rt Rt R	152	CSB9	l a	12 ← -a ₁₂				
154 Rt	153	ST03	"	a ₁₁	209 GSB5			
155 S104 156 RCL2 157 RCL1 158 RCL8 159 RCLB 159 RCLC 160 SSB9 161 S10B 162 RJ 162 RJ 163 STOC 164 RCL2 165 RCL1 166 RCL6 167 RCL1 166 RCL6 167 RCL7 168 SSB9 ■ a21 ← a21 ← a21 ← a21 ← a21 ← a21 ← a21 ← a22 ← det a a22 ←		R‡					1	
156 RCL2 212 F8° RCL1 213 PRTX 214 F8° RCL5 215 RTN 215 RTN 215 RTN 215 RTN 215 RTN 215 RTN 216 RTS RTN			1				1	
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$			1-				IE flag 0	
158			1					NT
159			1					
166 C589 161 STOB 162 R4 163 STOC 164 RCL2 165 RCL1 166 RCL6 167 RCL7 168 C589 LABELS LABELS LABELS FLAGS SET STATUS A θ _{ij} †h _{ij} †ij B CB+CE CB+CC CB			1				L ELSE DISI	LAY.
162 RJ 163 STDC 164 RCL2 165 RCL1 166 RCL6 167 RCL7 168 GSB9 LABELS FLAGS SET STATUS A B ₁₁ th ₁₁ tij B CB+CE CB+CC CB+			1.	_ a ₂₁			1	
162 RJ 163 STDC 164 RCL2 165 RCL1 166 RCL6 167 RCL7 168 GSB9 LABELS FLAGS SET STATUS A B ₁₁ th ₁₁ tij B CB+CE CB+CC CB+			a ₂	21 - 311			1	
163 STOC 164 RCL2 165 RCL1 166 RCL6 167 RCL7 168 SSP9 LABELS LABELS FLAGS SET STATUS A θ _{ij} th _{ij} tij B CB+CE CB+CC C CE+CC C CB+CC CB+CC C CB	162	BT 2.00	1	-11				
164			1		218 R/S			
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$			-				1	
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$			1					
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$			1	det a				
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$			a ₂	12 +				
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$				~11			I	
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	168	6589			L		L	
a b CB→CE CB→CC d CE→CC e 1 ON OFF O NO OFF O N			To				SET STATUS	
a b CB \rightarrow CE c CB \rightarrow CC d CE \rightarrow CC e 1 ON OFF O SO DEG SO FIX D			IC CR+CC	CE+CC F	RINT [h] O PRINT	FLAGS	TRIG	DISP
0 10 DEG 10 FIX D	^A θ _{ij} †h _{ij} †ij	B CB←CE	I CD CC					J.U.
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	^A θ _{ij} †h _{ij} †ij	00 00		d CE - CC	[1	ON OFF	l	
5 DISPLAY 6 7 [h] ≠[y] 8 CADD 9 CMULT 3 2 ⊠ RAD □ ENG 🕏 n 3	^A θ _{ij} †h _{ij} †ij a	p CB→CE	c CB→CC	02.00	1	0 k 🗆		FIX 🗆
I DISPLACE [IN] ← [I	a	p CB→CE	c CB→CC	02.00	2	0 k	GRAD □	SCI 🗆
	a 0 [h] → [y] '	b CB→CE	c CB→CC	3 4		0 🔊 🗆 1 🗆 🗷 2 🗆 🗷	GRAD □	SCI 🗆

^		B M ₂₁	, T ₂₁ '	C θ ₂	<u>Ι</u> ,, ΔΤ ₂₁ '	D M ₂₂ , T ₂		E	θ ₂₂ , ∠ T ₂₂ '		l poi	inter	
S0	S1	S2		S3	1 1	S5	S6		S7	S8		S9	
0 Z ₀	1 M11,T	11' 2 θ1	1,LT11'	³ M ₁₂ , T ₁₂ '	4 θ ₁₂ , ∠T ₁₂ '		6 ∠ 2/D		7	8		9	
#3£	P281				REGIS	112 STERS	ST×1			Cor	npute (I	1	\dashv
855 856	CHS GSB1		1"	T] = -[S]		111	RCL0			Con	npute (1	r'1	
₽54	1			= -1		110	CSB6				L٥	1] "	
853	STOO					109	GSB3			Т=	[(S)	
851 852	ST01 *LBLC		- S-			197 198	1 CHS			ξ=	- <u> </u>	٦.	
850	CHS		(S	S] = -[T']		186	STOP			S→			
049	1		ξ:	= -1		105	*LBLE						
848	€SB€		l c	ompute [T']		104	RTH			[1]	- lo	1 ('')	
846 847	1/X CSB1		ξ: (7	= 1/Z ₀ T] = [Z]/Z ₀		102 103	ST×1 ST×3			(T)	← [ξ	0] [T]	
845	ST00		1	→S		101	*LBL3						
844	*LBLc		-	- <u>-</u>		100	CHS			ξ=			
843	RTH		Ι'	o	ξ] · · ·	89 9	1			Cor	npute [1	r')	
842	CSB4		n l	r] ← [‡]	(T)	898	CSB6				h ₂₁	h ₂₂ Z ₀	
848 841	#LBL1 CSB3		ı	Γε	٥٦	896 897	ST OD			[T]	•		(H)
839	1/X		ξ ·	= 1/Z ₀ ; [Y]	= [T']/Z ₀	895	RCLD				7.	h ₁₂	1
838	RCLO		۱à	ompute [T']		894	ST÷1				h ₁₁	7	
837	ESB6		ĺπ	T] = [S]		893	STOO			H→	S		-
835 836	*LBLB STOR		s-			891 892	RTH ≉LBLe			_	_		
834	€TO€		C	ompute [T']	; [S] = [T']	898	STOD				t21'	Z ₀ t ₂₂ '	
933	CSB1		(1	$T] = Z_0 [Y]$		689	×			G=	Ζ,		
832	STOO		- 1'	•		987 988	RCLD				t11	t12'	
636 631	RTN ≉LBLb		-	 '→S		88£ 887	RCL0 ST÷1				г. ,	٠,	
829	STOI					885	ESB6		- 1	Cor	npute (1	Γ']	
627 628	-					884	SSB4		1		-	-	
	1		- 1			98Z	CHS			(.,	Lo	-1] "	
825 826	x 2		- 1			981 982	ST08			[T]	- '	(S)	
824	2		re	egister location	on.	888	*LBLD			Ę =	-1 Γ₁	٦٦	
823	#LBL@			ubroutine to		0 79	RTN			S→			
822	RTN		-			878	STOD						
821	R/S		["	DISPLAY.		876 877	X						
819 828	FO? RTN		l e	LSE		875 876	LSTX RCLD						
618	PRTX		Ι"	HEN PRINT		874	STOR						
817	FØ?		IF	F flag O		073	x				Lο	ŧJ	
816	*LBL5			ISPLAY RO	UTINE	872	KULB X Z Y			[T]	$\leftarrow \begin{bmatrix} 1 \\ 0 \end{bmatrix}$	(T)	
814 815	CSB5 X≇Y		- 1			870 871	*LBL4 RCLB				Г1	٥٦	
013	RCL:		- 1			969 870	CHS						
0 12	ISZI		- 1			868	1			ξ=	-1		
011	RCL:		ij-	→θ _{ij} , M _{ij}		867	€SB€				npute [7	Γ']	
810	ESB0		١٢	nspidy outpu	ı uală.	866	STOD						
888 889	RTN *LBLA		-	isplay outpu		9 64 965	RCLD X				921	922/2	ال"
887	STO:		1			863	1/%			[T]		g ₂₂ /2	,
88€	R↓		ı			962	STX1			(- '		911 912	
005	ISZI					86 1	STOR			G→	· _		_
884	STOI		1			969	*LBLd						
982 983	ESB6		Si	tore input da	ta.	658 659	RCL8 CT01			(Z)	= Z ₀ [7	Γ']	
801	*LBL a		۱.			85 7	CSB6		1	= ٤	Z _o		

113									
	1/X			_	169	XZY			
	CLD	1 1	t11'Z0 t1	ا 🖪 ر	178				
115	X	, .	-11 -0 -1	' II	171				
	TOD	[H] =	, t ₂	' []	172			1	
		1 1	t21' =	_				ı	
	RTN	1 1	_ Z,	ال	173				
	BL6			1	174			١.	
	CL2		ne to compute	e	175			t21'	
120 RI	CL!	[T'].		- 1	176	XZY		1	
121 6	SB7	1		- 1	177	STOC			
	T05	1		- 1	178	RCL1		1	
	XZY	1		- 1	179	RCLD		Rearrange t	u' and taa'
	T06	1		- 1	180	ST01			11 122
		1		- 1		X₹Y			
	CLE	ı		- 1	181			1	
	CLD	1		- 1	182				
	S87	1		- 1	183				
	CL5	1		- 1	184	RCLE			
129 R	CT 6	ı		- 1	185	ST02			
130 C	SB9	1		- 1	18€	X ≠ Y			
	T05	1		- 1	187	STOE			
	XZY	1		- 1	188	RTH		l	
	T06	1		- 1	189	#LBL5		Cubrouting t	multiply by
		1		- 1				2/D and add	
	CL4	1		- 1	190	RCL5		2/D and add	-1 L U.
	CT3	1		- 1	191	RCL€		1	
	CTB	1		- 1	192	ESB9		1	
137 R	CTC	1			193	0		l	
138 G	SB9	1		- 1	194	ENTT			
	CHS	1			195	1		l	
	CT 6	1		- 1	196	CMS			
	CL5	1			197	CTOS		l	
		1				#LBL?		Subrautian t	
	SBE	1			198			Subroutine to	o add I∠U.
143	.2	1			199			1	
144	÷	ı		- 1	200	ENT†			
	1/X	١,		- 1	201	1			
146 S	T05	2 D		- 1	282	*LBL8			
147	X = Y	D		- 1	293	÷₽		Subroutine to	add com-
148	CHS	1		- 1	204	R.J.		plex numbers	i.
	T06	1			205	R↓		1.	
	CIF	ı				AD.		l	
	CLE				2 8 6	→R			
151 R	CLD				286 287	X≇Y			
151 Ri 152 G	CLD SB7				2 8 6 28 7 2 8 8	XZY R4			
151 R 152 G 153 G	CLD SB7 SB5				286 287 288 289	X2Y #4			
151 RI 152 GI 153 GI 154 SI	CLD SB7 SB5 TOD	t111'			286 287 288 289	X2Y R1 + R1			
151 RI 152 GI 153 GI 154 SI 155 SI	CLD SB7 SB5 TOD X2Y	t11'			206 207 208 209 210 211	X2Y R1 + R1 +			
151 RI 152 GI 153 GI 154 SI 155 SI	CLD SB7 SB5 TOD	t ₁₁ '			206 207 208 209 210 211 212	X2Y R1 + R1 + R1			
151 Ri 152 Gi 153 Gi 154 Si 155 Si 156 Si	CLD SB7 SB5 TOD X2Y	t11'			206 207 208 209 210 211	X2Y R1 + R1 +			
151 Ri 152 Gi 153 Gi 154 Si 155 Si 156 Si	CLD SB7 SB5 TTOD X2Y TOE CL2	t11'			206 207 208 209 210 211 212	X2Y R1 + R1 + R1			
151 Ri 152 Gi 153 Gi 154 Si 155 I 156 Si 157 Ri 158 Ri	CLD SB7 SB5 TOD X2Y TOE CL2 CL1	t11'			206 207 208 209 210 211 212 213 214	X2Y R↓ + R↓ + R↑ →P RTN		Subscutice	a mutinly
151 Ri 152 Gi 153 Gi 154 Si 155 Si 156 Si 157 Ri 158 Ri 159 Gi	CLD SB7 SB7 STOD X2Y TOE CL2 CL1 SB7	t11'			286 287 288 289 210 211 212 213 214 215	X2Y R↓ + R↓ + R↑ +P RTN #LBL2		Subroutine to	o multiply
151 Ri 152 G 153 G 154 S 155 S 156 S 157 Ri 158 Ri 159 G	CLD SB7 SB5 TOD X2Y TOE CL2 CL1 SB7 SB5				286 287 288 289 210 211 212 213 214 215 216	X2Y R1 + R1 + P RTN #LBL2 RCL5		Subroutine to by 2/D.	o multiply
151 Ri 152 Gi 153 Si 154 Si 155 Si 156 Ri 157 Ri 158 Ri 159 Gi 160 Si	CLD 587 587 5700 XZY TOE CL2 CL1 587 587 587	t ₁₁ '			286 287 288 289 210 211 212 213 214 215 216 217	X2Y R1 + R1 + P RTM #1B1.2 RC1.5 RC1.6		by 2/D.	
151 Ri 152 G 153 S 154 S 155 S 156 S 157 Ri 158 Ri 159 G 160 C 161 S	CLD 587 585 5700 XXY TOE CL2 CL1 587 585 701 XXY				286 287 288 289 210 211 212 213 214 215 216 217 218	X2Y R1 + R1 +P RTN #LBL2 RCL5 RCL6 #LBL9		by 2/D. Subroutine to	
151 Ri 152 G: 153 S: 154 S: 155 S: 156 Ri 158 Ri 159 G: 160 G: 161 S: 162 S:	CLD SSB7 SSB5 TOD X2Y TOE CL1 SSB7 SSB7 TO1 X2Y TO2				286 287 288 289 210 211 212 213 214 215 216 217 218 219	X2Y R1 + R1 + R1 RTIN #LBL2 RCL5 RCL5 RCL6 #LBL9		by 2/D.	
151 Ri 152 G: 153 G: 154 S: 155 S: 157 Ri 158 Ri 159 G: 160 G: 162 S: 164 Ri	CLD SB7 SB5 TOD XB7 TOE CL2 CL1 SB7 SB5 TO1 XB7 TO2 CL4				286 287 288 289 211 212 213 214 215 216 217 218 219 228	X2Y R1 + R1 +P P RTM #LBL2 RCL5 RCL6 #LBL9 R1 X		by 2/D. Subroutine to	
151 Ri 152 G: 153 G: 154 S: 156 S: 157 Ri 159 G: 169 G: 161 S: 162 S: 163 S: 164 Ri	CLD S87 S85 S170 S87 TOE CL2 CL1 S87 S85 TO1 XXY TO2 CL4 CL4 CL3				286 287 288 289 210 211 212 213 214 215 217 218 219 229	X2Y R1 + R1 + R1 RTIN #LBL2 RCL5 RCL5 RCL6 #LBL9		by 2/D. Subroutine to	
151 Ri 152 G: 153 G: 154 S: 155 S: 156 S: 157 Ri 158 G: 169 S: 162 S: 163 S: 164 Ri 165 R:	CLD SSE7 SSE5 STOD X2Y TOE CL2 CL1 SSE7 SSE5 STD1 X2Y TO2 CL4 CL3 CL4 CL3 CC4				286 287 289 210 211 212 213 214 215 216 217 218 219 220 220	X2Y R1 ++ R1 +P RTH REL2 RCL5 RCL6 *LBL9 R1 X R1		by 2/D. Subroutine to	multiply
151 Ri 152 G: 153 G: 154 S' 155 S' 157 Ri 159 Ri 169 G: 161 S' 162 S' 164 Ri 165 Ri 166 C:	CLD S87 S85 S170 S87 TOE CL2 CL1 S87 S85 TO1 XXY TO2 CL4 CL4 CL3	t ₂₂ '			286 267 289 210 211 212 213 214 215 216 217 218 229 220 221 222 223	X2Y R1 + R1 +P P RTM #LBL2 RCL5 RCL6 #LBL9 R1 X		by 2/D. Subroutine to	
151 Ri 152 G: 153 G: 154 S' 155 S' 157 Ri 158 Ri 168 G: 162 S' 163 S' 164 Ri 165 Ri 165 Ri	CLD S87 S87 S85 T00 X27 T0E CL2 CL1 S87 S85 T01 X27 T02 CL4 CL3 CL4 CL3 CHS S82				286 287 289 210 211 212 213 214 215 216 217 218 219 220 220	X2Y R1 ++ R1 +P RTH REL2 RCL5 RCL6 *LBL9 R1 X R1		by 2/D. Subroutine to	
151 Ri 152 G: 153 G: 154 S' 155 S' 157 Ri 158 Ri 168 G: 162 S' 163 S' 164 Ri 165 Ri 165 Ri	CLD SSE7 SSE5 STOD X2Y TOE CL2 CL1 SSE7 SSE5 STD1 X2Y TO2 CL4 CL3 CL4 CL3 CC4	t ₂₂ '	LS		286 267 289 210 211 212 213 214 215 216 217 218 229 220 221 222 223	X2Y R1 + R1 +P RTH #LBL2 RCL5 RCL5 RCL6 #LBL9 R1 X R1 R1 R1 R1 R1	T	by 2/D. Subroutine to complex num	
151 Ri 152 G: 153 G: 154 S: 155 S: 156 S: 157 Ri 159 G: 161 S: 162 S: 163 S: 164 Ri 165 Ri 166 C: 166 C:	CLD SSE7 SSE5 STOD X21 TOE CL2 CL1 SSE7 SSE5 TO1 X27 TO2 CL3 CL3 CL4 CL3 CC4 CC5 CC5 CC5 CC5 CC5 CC5 CC5 CC5 CC5	t ₂₂ ' t ₁₂ ' LABE		F s-	286 287 288 289 210 211 212 213 215 216 217 218 219 220 221 222 223 224	XIY R1 + R1 + R1 + P RTN #LBL2 RCL5 RCL6 #LBL9 R1 X R1 R1 RTN FLAGS	T	by 2/D. Subroutine to complex num	o multiply bers.
151 Ri 152 G: 153 G: 154 S: 155 S: 156 S: 157 Ri 158 Ri 159 G: 160 S: 162 S: 163 S: 164 Ri 165 Ri 165 S: 166 S: 167 G: 168 S:	CLD S87 S85 S700 X27 T0E CL2 CL1 S87 S85 T01 X27 T02 CL4 CL3 CKS S82 T03 S S > Y	t ₁₂ ' t ₁₂ ' LABE Z	S→G	E S-	286 287 288 289 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224	X2Y R1 + R1 +P RTH #LBL2 RCL5 RCL5 RCL6 #LBL9 R1 X R1 R1 R1 R1 R1	FLAGS	by 2/D. Subroutine to complex num	
151 Ri 152 G: 153 G: 154 S: 155 S: 156 S: 157 Ri 159 G: 161 S: 162 S: 163 S: 164 Ri 165 Ri 166 C: 166 C:	CLD S87 S85 S700 X27 T0E CL2 CL1 S87 S85 T01 X27 T02 CL4 CL3 CKS S82 T03 S S > Y	t ₂₂ ' t ₁₂ ' LABE Z G G G G G G G G G G G G	S→G G→S		286 287 289 210 211 212 213 214 215 216 217 218 229 221 222 223 224 +H	X2Y R1 + R1 + R1 + R1 + R1 - R1 - R1 - R1 -	T	by 2/D. Subroutine to complex num SET STATUS TRIG DEG 🖾	o multiply bers. DISP
151 Ri 152 G: 153 G: 154 S: 155 S: 156 S: 157 Ri 158 Ri 159 G: 160 S: 162 S: 163 S: 164 Ri 165 Ri 165 S: 166 S: 167 G: 168 S:	CLD S87 S85 S700 X27 T0E CL2 CL1 S87 S85 T01 X27 T02 CL4 CL3 CKS S82 T03 S S > Y	t ₁₂ ' LABE Z D	S→G G→S	е н	286 287 289 210 211 212 213 214 215 216 217 218 229 221 222 223 224 +H	XIY R1 + R1 + R1 + P RTN #LBL2 RCL5 RCL6 #LBL9 R1 X R1 R1 RTN FLAGS	FLAGS ON OFF 0 & □ 1 □ ₽	by 2/D. Subroutine to complex num SET STATUS TRIG DEG © GRAD	DISP
151 Ri 152 G: 153 G: 154 S: 155 S: 156 S: 157 Ri 158 Ri 169 C: 160 S: 162 S: 163 S: 164 Ri 165 Ri 165 S: 166 S: 167 G: 168 S:	CLD SSE7 SSE5 STOD XZY TOE CL2 CL1 SSE7 SSE5 T01 XZY T02 CL4 CL3 CH5 SSE2 T03 SS+Y CS+ CH5 SSE2 T03 CS+ CH5 SSE2 T03 CS+ CH5 SSE2 T03 CS+ CH5 SSE2 T03 CS+ CH5 SSE2 T03 CS+ CH5 SSE2 T03 CS+ CH5 SSE2 T03 CS+ CH5 SSE2 T03 CS+ CH5 SSE2 T03 CS+ CS+ CS+ CS+ CS+ CS+ CS+ CS+ CS+ CS+	t ₁₂ ' t ₁₂ ' LABE Z D	S→G G→S Used	e H-	286 287 289 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 +H	X2Y R1 + R1 + R1 + R1 + R1 - R1 - R1 - R1 -	FLAGS ON OFF	by 2/D. Subroutine to complex num SET STATUS TRIG DEG 🖾	o multiply bers. DISP

Fourier Series

001	*LPLa	START	05 7 9	5105
		SIANI	058 1/X	ELSE
002	CLRG	1		DISPLAY 0.111.
003	P≢S	l	059 RTH	
084	CLRG	1	868 *LEL8	
885	RAD		061 R/S	DISPLAY new k.
89€	RTN		062 GTOC	
		N↑# fregs		
007	*LBLA	NI# freqs	063 #LBLd	PRINT POLAR
888	2		064 SF1	1
		ł		1
889	x	l .	065 RCLE	1
818	STOE		066 STDI	1 1
				1
011	XZY		867 CT02	
012	STOE		868 *LBLD	PRINT RECTANGULAR
				1
813	RTH		069 CF1	1
814	*LBLE	J	970 RCLB	1
				1
e15	STOD	Store J	871 STOI	
816	1		072 *LBL2	BEGIN loop 2.
		I		Dedit loop 2.
817	ST00	INITIALIZE k	073 RCLI	
8 18	RTN	l	074 RCLB	1
				1
819	*LBLC	Yk	875 -	1
82€	STOC	Store yk	8 7€ 2	1
		7 K		[
821	RCLB	I	€77 CHS	1
822	STOI	INITIALIZE pointer	078 ÷	ı
				1
823	*LBL1	BEGIN loop 1.	079 RCLD	1
824	CLX	· ·	886 +	1
		ł		1
825	RCL0	1	081 FIX	1
82€	RCLI	1	l 082 DSP0	1
				1
827 828	RCLE			
028	-	1	l 084 DSP3	1
829	2	l	085 RCL;	1
		l		1
e3e	CHS	l	88€ DSZI	1
831	÷	l	087 RCL;	1
832	DOLD.	l		ł I
	RCLD	l	088 F1?	IF print polar
			1 000 11:	
	+	1		
83 3	•		889 GT03	THEN GO TO LBL 3
833 834	RCLE		889 GT03 890 2	THEN GO TO LBL 3
83 3	•		889 GT03 890 2	THEN GO TO LBL 3 ELSE
833 834 835	RCLE ÷		089 GT03 090 2 091 RCLE	THEN GO TO LBL 3 ELSE Prepare to print
833 834 835 83€	RCLE ÷ ×		089 GT03 090 2 091 RCLE 092 ÷	THEN GO TO LBL 3 ELSE
833 834 835	RCLE ÷		089 CT03 090 2 091 RCLE 092 ÷ 093 x	THEN GO TO LBL 3 ELSE Prepare to print
833 834 835 83€ 837	RCLE ÷ × 2		089 CT03 090 2 091 RCLE 092 ÷ 093 x	THEN GO TO LBL 3 ELSE Prepare to print
833 834 835 83€ 837 838	RCLE ± × 2 ×		889 GT03 896 2 891 RCLE 892 ÷ 893 × 894 XZY	THEN GO TO LBL 3 ELSE Prepare to print
833 834 835 83€ 837 838 839	RCLE ÷ × 2 × Pi		889 CT03 896 2 891 RCLE 892 ÷ 893 × 894 M2Y 895 LSTM	THEN GO TO LBL 3 ELSE Prepare to print
833 834 835 83€ 837 838	RCLE ± × 2 ×		889 CT03 896 2 891 RCLE 892 ÷ 893 × 894 M2Y 895 LSTM	THEN GO TO LBL 3 ELSE Prepare to print
833 834 835 83€ 837 838 839 848	RCLE ÷ × 2 × Pi x		889 CT03 896 2 891 RCLE 892 ± 893 x 894 M2Y 895 LSTM 896 x	THEN GO TO LBL 3 ELSE Prepare to print
833 834 835 83€ 837 838 839 848	RCLE ±		889 ST03 896 2 891 RCLE 892 ± 893 × 894 X2Y 895 LSTX 896 × 897 *LEL4	THEN GO TO LBL 3 ELSE Prepare to print
833 834 835 83€ 837 838 839 848	RCLE ÷ × 2 × Pi x		889 ST03 896 2 891 RCLE 892 ± 893 × 894 X2Y 895 LSTX 896 × 897 *LEL4	THEN GO TO LBL 3 ELSE Prepare to print rectangular.
833 834 835 836 837 838 839 848 841 842	RCLE †		889 CT03 896 2 891 RCLE 892 ± 893 x 894 X2Y 895 LSTX 896 x 897 *LEL4 888 X2Y	THEN GO TO LBL 3 ELSE Prepare to print rectangular.
833 834 835 836 837 839 849 841 842 843	RCLE ± 2 x P: x xzy +R ST+i		889 CT03 896 2 891 RCLE 892 ÷ 893 x 894 MZY 895 LSTX 896 x 897 *LBL4 898 XZY 899 CSB5	THEN GO TO LBL 3 ELSE Prepare to print rectangular.
833 834 835 836 837 839 849 840 841 842 843	RCLE †		889 CT03 896 2 891 RCLE 892 ± 893 x 894 X2Y 895 LSTX 896 x 897 *LEL4 888 X2Y	THEN GO TO LBL 3 ELSE Prepare to print rectangular.
833 834 835 836 837 839 849 841 842 843	RCLE ± 2 X P: XZY +R ST+i XZZY		889 CT03 896 2 891 RCLE 892 ÷ 893 × 894 X2Y 895 LSTX 896 × 897 *LEL4 898 X2Y 899 GSB5 188 R1	THEN GO TO LBL 3 ELSE Prepare to print rectangular.
833 834 835 836 837 838 839 849 841 842 843 844	RCLE 2 X Pi X X X Y S S S S S S S S S S S S		889 CT03 899 C2 891 RCLE 892 * 893 X 894 X2Y 895 LSTX 896 X 897 *LEL4 898 X2Y 899 CSB5 100 R1 101 CSB5	THEN GO TO LBL 3 ELSE Prepare to print rectangular.
833 834 835 836 837 839 849 841 842 843 844 845	RCLE ± 2 x P; xxy +R ST+; xzy DSZI ST+;		889 CT03 896 2 891 RCLE 892 ÷ 893 × 894 X2Y 895 LSTX 896 × 897 *LEL4 898 X2Y 899 GSB5 188 R1	THEN GO TO LBL 3 ELSE Prepare to print rectangular.
833 834 835 836 837 839 849 841 842 843 844 845	RCLE ± 2 x P; xxy +R ST+; xzy DSZI ST+;		889 CT03 896 2 891 RCLE 892 ÷ 893 x 894 MZY 895 LSTX 896 x 897 *LEL4 898 XZY 899 CSB5 188 RI 181 CSB5 182 F87	THEN GO TO LBL 3 ELSE Prepare to print rectangular.
833 834 835 836 837 839 849 841 842 843 844 845 846	RCLE ± 2 Pi x=y +R ST+i ST+i RCLC		889 GT03 896 2 891 RCLE 892	THEN GO TO LBL 3 ELSE Prepare to print rectangular.
833 834 835 836 837 838 839 841 842 843 844 845 846 847	RCLE 2 X P: XZY >R ST+: XZY DS21 ST+: RCLC EMT+		889 CT03 896 2 891 RCLE 892 ÷ 893 x 894 MZY 895 LSTX 896 x 897 *LEL4 898 XZY 899 CSB5 188 RI 181 CSB5 182 F87	THEN GO TO LBL 3 ELSE Prepare to print rectangular.
833 834 835 836 837 839 849 841 842 843 844 845 846	RCLE ± 2 Pi x=y +R ST+i ST+i RCLC	JE pointer ≠ 0	889 CT03 896 2 891 RCLE 892 * 893 X 894 M2Y 895 LSTX 896 X 897 *LBL4 898 X2** 899 CSB5 188 R1 181 CSB5 182 F82 183 SPC 184 DSZ1	THEN GO TO LBL 3 ELSE Prepare to print rectangular.
833 834 835 837 839 849 841 842 843 844 845 845 848 848	RCLE ± 2 × P: XZY +P: XZY +P: ST+: XZY DSZI SST+: RCLC ENT† DSZI	IF pointer ≠ 0	889 ST03 896 2 891 RCLE 892 ÷ 893 x 894 MZY 895 LSTX 896 x 897 *LEL4 898 XZY 899 GSB5 108 R4 181 SSB5 182 F87 183 SPC 184 DSZI 185 ST02	THEN GO TO LBL 3 ELSE Prepare to print rectangular. IF pointer ≠ 0 THEN REPEAT loop 2.
823 834 835 836 837 838 839 841 842 843 844 845 846 846 849	RCLE 2 X P: XZY >R ST+: XZY DS21 ST+: RCLC EMT+	IF pointer ≠ 0 THEN REPEAT loop 1.	889 CT03 896 2 891 RCLE 892 * 893 X 894 M2Y 895 LSTX 896 X 897 *LBL4 898 X2** 899 CSB5 188 R1 181 CSB5 182 F82 183 SPC 184 DSZ1	THEN GO TO LBL 3 ELSE Prepare to print rectangular.
833 834 835 837 839 849 841 842 843 844 845 845 848 848	RCLE ± 2 × P: XZY +P: XZY +P: ST+: XZY DSZI SST+: RCLC ENT† DSZI	THEN REPEAT loop 1.	889 CT03 896 2 891 RCLE 892 ± 894 X2Y 895 LSTX 896 X 897 #LEL4 898 X2Y 899 GSB5 188 R1 181 GSB5 182 F87 183 SPC 184 DSZ1 185 GT02 186 RTN	THEN GO TO LBL 3 ELSE Prepare to print rectangular. IF pointer ≠ 0 THEN REPEAT loop 2.
823 834 835 836 827 839 849 841 842 843 844 845 845 849 859	RCLE		889 CT03 896 2 891 RCLE 892 ÷ 893 x 894 M2Y 895 LSTX 896 x 897 *LEL4 898 X2Y 899 CSB5 188 RI 181 CSB5 182 F87 184 SSPC 184 SSZI 185 SPC 184 DSZI 185 CT02 186 RTN 187 *LEL3	THEN GO TO LBL 3 ELSE Prepare to print rectangular. IF pointer ≠ 0 THEN REPEAT loop 2.
833 834 835 836 837 839 841 842 843 844 845 846 847 849 858 858	RCLE ± 2 X P: XZY +R ST+: XZY ST+: RCLC ENT+ DSZI GT01 1 ST+8	THEN REPEAT loop 1.	889 ST03 896 2 891 RCLE 892 ÷ 893 x 894 MZY 895 LSTX 896 x 897 *LEL4 898 XZY 899 GSB5 106 RI 181 GSB5 182 F87 183 SPC 184 DSZI 185 GT02 186 RTN 187 *LBL3 188 XZY	THEN GO TO LBL 3 ELSE Prepare to print rectangular. IF pointer ≠ 0 THEN REPEAT loop 2.
823 834 835 836 827 839 849 841 842 843 844 845 845 849 859	RCLE	THEN REPEAT loop 1.	889 ST03 896 2 891 RCLE 892 ÷ 893 x 894 MZY 895 LSTX 896 x 897 *LEL4 898 XZY 899 GSB5 106 RI 181 GSB5 182 F87 183 SPC 184 DSZI 185 GT02 186 RTN 187 *LBL3 188 XZY	THEN GO TO LBL 3 ELSE Prepare to print rectangular. IF pointer ≠ 0 THEN REPEAT loop 2.
833 834 835 837 839 849 841 844 845 846 847 848 849 859 859	RCLE ± 2 Pi XZY +R SI+i SSZI SSZI ST+i DSZI ENT+ DSZI GT01 ST+0 RCLE	THEN REPEAT loop 1.	889 CT03 899 CT03 8991 RCLE 8992 * 8993 X 8994 M2Y 8996 X 8997 *LEL4 8998 X2** 8999 GSB5 1808 R1 1811 GSB5 1802 FBP2 1803 SPC 1804 DSZI 1805 RTN 1807 *LBL3 1808 X2** 1809 YP	THEN GO TO LBL 3 ELSE Prepare to print rectangular. IF pointer ≠ 0 THEN REPEAT loop 2.
833 834 835 836 839 849 841 842 843 844 845 846 847 849 859 859	RCLE ± 2 X P: XZY FR ST+: XZY DSZI SST+: RCLC ENT+ DSZI GTO1 ST+0 RCLE RCLE RCLE	THEN REPEAT loop 1. ELSE INCREMENT k.	889 CT03 896 2 891 RCLE 892 ÷ 893 x 894 MZY 895 LSTX 896 x 897 *LEL4 898 XZY 899 CSB5 100 R1 101 CSB5 102 FB7 104 DSZI 105 CT02 106 RTN 107 LBL3 108 XZY 109 +P 110 2	THEN GO TO LBL 3 ELSE Prepare to print rectangular. IF pointer ≠ 0 THEN REPEAT loop 2.
833 834 835 836 838 838 849 841 844 844 845 845 845 845 845 855	RCLE ± 2 x P; x=y +R ST+i RCLC ENT† DS2I ST+0 RCLE	THEN REPEAT loop 1. ELSE INCREMENT k. IF k ≤ N	889 ST03 896 2 891 RCLE 892 # 893 X 894 MTY 895 LSTX 896 X 897 #LEL4 898 X2V 899 GSB5 100 RI 101 GSB5 102 F87 103 SPC 104 DSZI 105 GT02 106 RTN 107 #LBL3 108 XZY 109 PP 110 2 111 RCLE	THEN GO TO LBL 3 ELSE Prepare to print rectangular. IF pointer ≠ 0 THEN REPEAT loop 2.
833 834 835 836 839 849 841 842 843 844 845 846 847 849 859 859	RCLE ± 2 X P: XZY FR ST+: XZY DSZI SST+: RCLC ENT+ DSZI GTO1 ST+0 RCLE RCLE RCLE	THEN REPEAT loop 1. ELSE INCREMENT k.	889 CT03 896 2 891 RCLE 892 ÷ 893 x 894 MZY 895 LSTX 896 x 897 *LEL4 898 XZY 899 CSB5 100 R1 101 CSB5 102 FB7 104 DSZI 105 CT02 106 RTN 107 LBL3 108 XZY 109 +P 110 2	THEN GO TO LBL 3 ELSE Prepare to print rectangular. IF pointer ≠ 0 THEN REPEAT loop 2.
833 834 835 836 838 838 849 841 844 844 845 845 845 845 845 855	RCLE ± 2 x P; x=y +R ST+i RCLC ENT† DS2I ST+0 RCLE	THEN REPEAT loop 1. ELSE INCREMENT k . IF $k \le N$ THEN GO TO LBL 0	889 CT03 899 CT03 899 CT03 8991 RCLE 892 ÷ 8993 x 8994 M2Y 8995 LSTX 8996 x 897 *LEL4 8999 CSB5 1808 R1 1811 CSB5 182 F87 1841 SSPC 1841 SSPC 1841 ST21 185 CT02 1867 RTN 1877 *LEL3 1888 X2Y 189 9 110 2 1111 RCLE	THEN GO TO LBL 3 ELSE Prepare to print rectangular. IF pointer ≠ 0 THEN REPEAT loop 2.
833 834 835 836 839 849 841 842 844 845 849 851 852 853 855 854	RCLE	THEN REPEAT loop 1. ELSE INCREMENT k. IF k N THEN GO TO LBL 0 REGIS	889 CT03 896 2 891 RCLE 892 ÷ 893 x 894 M2Y 895 LSTX 896 x 897 *LBL4 898 X2Y 899 CSB5 180 R1 181 CSB5 182 F87 184 DSZ1 185 GT02 186 RTN 187 SPC 188 SYC 189 P 110 2 111 RCLE 1112 ÷	THEN GO TO LBL 3 ELSE Prepare to print rectangular. IF pointer ≠ 0 THEN REPEAT loop 2. Convert (a, b) to (c, θ)
833 834 835 836 839 849 841 842 843 844 845 849 851 852 853 855	RCLE	THEN REPEAT loop 1. ELSE INCREMENT k . IF $k \le N$ THEN GO TO LBL 0	889 CT03 896 2 891 RCLE 892 ÷ 893 x 894 MZY 895 LSTX 896 x 897 *LBL4 898 XZY 899 CSB5 100 R1 101 SP5 102 F87 103 SPC 104 SSPC 105 SPC 106 RTN 107 *LBL3 108 RTN 107 *LBL3 108 XZY 109 *P 110 2 111 RCLE 1111 ÷	THEN GO TO LBL 3 ELSE Prepare to print rectangular. IF pointer ≠ 0 THEN REPEAT loop 2. ————————————————————————————————————
833 834 835 837 839 849 841 841 844 845 846 847 848 849 859 859 851 852 855	RCLE ± 2 X Pi X=Y +R ST+i X=Y DSZ1 ST+i DSZ1 ST+i BSZ1 ST+o BSZ1 ST+o BSZ1 ST+o BSZ1 ST-o ST-	THEN REPEAT loop 1. ELSE INCREMENT k. IF k ≤ N THEN GO TO LBL 0 REGIS 3 b 4 a S3 S4 S4	889 CT03 896 2 891 RCLE 892 \$ 894 M2Y 895 LSTN 896 X 897 *LBL4 898 X2** 899 CSB5 188 R1 181 CSB5 182 F82 184 DSZ1 185 GT02 186 RTN 187 *LBL3 188 X2** 189 P 110 2 111 RCLE 112 \$ STERS 5 b 6 a 7 b SS S6 S6	THEN GO TO LBL 3 ELSE Prepare to print rectangular. IF pointer $\neq 0$ THEN REPEAT loop 2. Convert (a, b) to (c, θ)
833 834 835 836 839 849 841 842 843 844 845 846 849 859 851 852 853 855	RCLE	THEN REPEAT loop 1. ELSE INCREMENT k . IF $k \le N$ THEN GO TO LBL 0 REGIS 3 b 4 a	889 GT03 896 2 891 RCLE 892 ± 893 x 894 MZY 895 LSTX 896 x 897 *LEL4 898 XZY 899 GSB5 188 RL 181 GSB5 182 FB7 183 SPC 184 DSZI 185 GT02 186 RTN 187 *LBL3 188 XZY 189 *P 110 2 111 RCLE 111 TCLE 55 b 6 a 7 b	THEN GO TO LBL 3 ELSE Prepare to print rectangular. IF pointer $\neq 0$ THEN REPEAT loop 2. Convert (a, b) to (c, θ)
833 834 835 836 837 838 839 849 841 842 844 845 845 845 855 855 855 856	RCLE ± 2 X Pi X=Y +R ST+i RCLC ENT† DS2I ST+i RCLC ENT† DS2I ST+i RCLC ENT† DS2I ST-i ST-i RCLC ENT† DS2I ST-i ST	THEN REPEAT loop 1. ELSE INCREMENT k. IF k N THEN GO TO LBL 0 REGIS 3 b 4 a S3 S4	889 CT03 899 CT03 899 CT03 899 CLE 892	THEN GO TO LBL 3 ELSE Prepare to print rectangular. IF pointer $\neq 0$ THEN REPEAT loop 2. Convert (a, b) to (c, θ)
833 834 835 837 838 839 849 841 841 844 845 846 849 859 859 859	RCLE ± 2 X Pi X=Y +R ST+i ST+i DSZI ST+i DSZI ST+i ST+i BCLC ENT+ DSZI ENT+ DSZI ENT+ DSZI ST-i ST	THEN REPEAT loop 1. ELSE INCREMENT k. IF k ≤ N THEN GO TO LBL 0 REGIS 3 b 4 a S3 b S4 a	889 CTO3 896 2 891 RCLE 892 \$\displaysty 894 M2Y 895 LSTA 896 X 897 *LEL4 899 CSB5 180 RJ 181 CSB5 182 F87 184 DSZI 185 SPC 184 DSZI 185 STO2 186 RTN 187 *LEL3 188 X2Y 189 3P 110 2 111 RCLE STERS 56 a 7 b S5 56 a 57 5 5 56 a 57 5 5 56 a 57 5 5 5 5 6 6 7 5 5 5 5 6 57 5 5 5 5 6 6 7 5 7 7 7 7 7 7 8 7 7 8 7 7 8 7 7 8 7 7 9 9 9 9 10 9 9 10 9 9 11 12 9 12 9 13 9 14 9 15 9 15 9 16 9 17 9 18 9 18 9 19 9 19 9 10 9 11 9 11 9 12 9 13 9 14 9 15 9 16 9 17 9 18	THEN GO TO LBL 3 ELSE Prepare to print rectangular. IF pointer $\neq 0$ THEN REPEAT loop 2. Convert (a, b) to (c, θ)

113 ×			169	PRTX		THEN PRI	NT
114 GT04			176			-	
115 *LBLE	t→f(t)		171	RTN		ELSE DISF	LAY
116 CF2 117 ST00			172			i	
118 RCLE			173				
119 STOI	INITI	ALIZE pointer	174	K/3			
120 CLX	_		.			1	
121 ∗LBL€	BEGIN	loop 6.					
122 RCLI 123 RCLB							
123 ROLE 124 -							
125 2							
12€ CHS			i				
127 ÷							
128 RCLD 129 +							
130 X=0?	IF i = i	n					
131 SF2		set flag 2.					
132 2			1				
133 ×							
134 Pi 135 x							
135 × 136 RCL0			1				
137 x							
138 RCLE							
139 ÷			- 1				
140 1 141 F2?	IF flag	2	- 1				
141 FZ? 142 GSB0		$a_0 \leftarrow a_0/2$.	1				
143 →R		40 4072	- 1				
144 RCL:			- 1				
145 x			İ				
146 XZY							
147 DSZI 148 RCL;			1				
149 x			1				
150 +			- 1			i	
151 RCLE 152 ÷			1				
153 2			- 1				
154 x			- 1				
155 +						l	
15€ DSZI		nter ≠ 0	.			l	
157 GT06 158 GSB5		REPEAT loop 6 DISPLAY f(t).	'				
159 F0?	1 2200	DISI EAT I(t).					
168 SPC			- 1				
161 RTN							
162 *LBL0 163 CLX		tine to replace 1	'				
164	with 0	.5.	- 1				
165 5			1				
166 RTN							
167 *LBL5 168 F0?	IF flag	AY ROUTINE 0				1	
100 10		BELS		FLAGS		SET STATUS	
A N1#freqs B J C	Yk	D RECT	E t→f(t)	O PRINT	FLAGS	TRIG	DISP
a START b c		d POLAR	е	1 POLAR	ON OFF	DEG 🗆	FIX 🗷
Used 1 Loop 2	Loop	3 →P	4 PRINT	² Used	1 🗆 🔣 2 🗆 🖔	GRAD □ RAD kŪ	SCI □
⁵ DISPLAY 6 Loop 7		8	9	3	3 🗆 K		ENG □ n <u>3</u>

Active Filter Design

001	*LBLa				857	RTN		
862	STO#		Store fo	li .	65 8	*LBLD		HIGH PASS
883	RTH				8 59	RCL3		Display C ₁
884	#LBLA		1		960	esb5		1
885	ST01		Store A		861	RCLO		l l
88€	RTM				862	x		
007	*LBLb		1		963	2		1
808	ST02		Store a		864	x		1
009	RTH				865	P;		1
010	*LBLB				966	x		i l
			Store C		867	ST04		1
011	ST03					RCL2		
812	RTH		LOW PA		968			1
813	*LBLC		LOWF	433	869	X≇Y		l .
014	RCL2		l		070	÷.		
815	2				871	2		i i
816	÷		l		672	RCL1		1
817	RCL1		l		873	1/X		1
818	÷		l		874	+		
019	2		l		675	÷		1
828	P.		l		87€	CSB5		Display R ₂
821	X		I		877	RCL3		
			ı		078	CSB5		Display C ₃
822	RCLO		1					l Display O3
823	X		l		079	RCL1		i i
824	RCL3		l		989	÷		1
825	x		l		081	esb5		Display C ₄
82€	STD4		l		882	RCL1		1
827	÷		l		983	2		1
828	ST05		l		884	x		1
829	CSB5		Display	R ₁	885	1		l i
838	RCL3		1		886	+		1
031	4		l		887	RCL2		1
832	x ⁷		l		888	÷		1
633	RCL1		l		889	RCL4		1
834	1		1		898	+		1
835	+		l		891	ESB5		Display R ₅
836	x		l					Display 113
			i		892	RTN		
637	RCL2		l		093	*LBLE		BAND PASS
638	Xs		l		894	RCL3		ł
839	÷		l		895	RCL0		1
840	ese5		Display	C ₂	89€	x		1
841	RCL2		l		897	2		
842	2		l		898	x		1
843	÷		l		899	Pi		
844	RCL1		l		190	x		1
845	1		1		100 101	ST04		
846	+		1		182	RCL1		1
847	÷		1		183	x		1
848	RCL4		1		184	RCL2		1
849	÷		1		185	X		1
858	CSB5		Display	R.	10€	1/8		Display R ₁
8 51	RCL1		Justian	,	107	GSB5		Sisping III
85 2	RCL5		1		108	2		1
65 3	x		1		109	RCL2		1
854	CSB5		Display	= R.	110	KULZ		1
65 5	RCT3		Jispiay	•••		**		1
85€	ESB5		Display	C.	111			1
F-626	435 3		Lispiay		STERS	RCL1		1
0 ,	Ti .	2	3 6	I4 .	51 2H5	6	7	T8 T9
o fo	' A	έ α	l, c	⁴ 2π f ₀ C	5 R _{1LP}	ľ	ľ	ľ ľ
S0	S1	S2	S3	S4	S5	S6	S7	S8 S9
1	Ι΄.	[1	Ī .	1	[
A	TE	3	Tc		D		TE .	1
1	1		ľ		l			ľ

113 114 115 116 117 118 119 129 121 122 123 124 125 126	RCL4 X RCL2 X L/X CSB5 RCL3 CSB5 CSB5 CSB5 CSB5 4 RCL4 ±	Disp	iay R ₂ ay C ₃ ay C ₄					
132 133 134 135 136 137	PRTX F#P: RTN R/S RTN R/S	ELSI	E ISPLAY.					
		L.	ABELS		FLAGS		SET STATUS	
^A A	ВС	C LP	D HP	E BP	⁰ PRINT	FLAGS	TRIG	DISP
a fo	bα	c	d	e	1	ON OFF		
0	1		3	4	2	0 🗷 🗆	DEG &	FIX 🗆
	İ	2	1			1 🗆 🛭	GRAD □ RAD □	SCI □
5 DISPLAY	6	7	8	9	3] 3 K		ENG ⊠
		·						

Butterworth or Chebyshev Filter Design

801	*LBLE				857	LI						
882	1		1		858	X						
983	ė		1		859	÷						
			1		868	STO				1		
884	÷									Na.	/	ethod root
885	10×		Compute order of		961	*LBL						etnoa root
006	2		Butterworth filter	.	862	REL				find	er.	
007	x				863	RCL:	3			l		
808	1				864	RCL	.			l		
009	•		1		865	Y				l		
			1			STO				l		
010	LN		i		066					l		
011	STOB				067	ENT				l		
012	XZY				06 8	1/	K			l		
013	GSB9				869	+				l		
014	GSB7				070	RCL	В			l		
					871	-				l		
015	RCLB					RCL				ı		
016	XZY				072					ı		
817	LN				073	ENT				ı		
018	ABS				074	1/	X			Į		
819	÷				075	-				l		
020	1				076	÷				l		
021	+				077	RCL	7			l		
			i			L				1		
022	2				078					1		
023	÷				079	÷				ł		
024	INT		Į.		080		2					
925	STOE		l		881	÷						
026	RTH				082	-						
827	*LBLA		Store R		083	STO	Ε					
					084	LST						
028	ST05				085	AB						
029	RTN				886	HD						
030	*LBLD											
031	1		l	.	087		0					
032	0		Compute order of		088		1					
033	÷		Chebyshev filter.		089	X≟Y	?					
034	10×		1		090	GT0	6					
					091	RCL				1		
075	1		1		092		2			l		
036			l			÷				l		
037	4				093					l		
038	x		1		094		1			l		
039	RCL6				095	+						
848	Χ²		Ì		096	IN						
041	 ÷				097	RT						
			Ì		898	*LBL	9			C	routine :	to multiply
042 043	_2				099		2					to multiply
	OTOD				180	X				by 2	2π.	
044	STOB						;			l		
045	XZY		1		101		-			l		
046	GSB9				102	X				l		
847	GSB7		1		103	R?				l		
					104	*LBL	7			Sub	routine	to compute
			1									frequency.
048	ENT †		1		105	STO	A			nor		
048 049	ENT† X2									nor		requeriey.
048 049 050	ENT †				196	RCL	D			nor		requeries.
048 049 050 051	ENT† X2 1				106 107	RCL STO	D I			nor		
048 049 050 051 052	ENT† X2 1 - IX				106 107 108	RCL STO	D I			nor		
048 049 050 051 052 053	ENT† X2 1 - IX +				106 107 108 109	RCL STO STO *LBL	D I i 4					
048 049 050 051 052	ENT† X2 1 - IX				106 107 108	RCL STO STO *LBL CSE	D I I 4 3					
048 049 050 051 052 053	ENT† X2 1 - IX +				106 107 108 109	RCL STO STO *LBL	D I I 4 3					
048 049 050 051 052 053 054 055	ENT†				106 107 108 109 110 111	RCL STO STO *LBL SSE STO	D I I I I I I I I I I I I I I I I I I I			Ban		
048 049 050 051 052 053 054	ENT† X2 1 - 1X + ST03			BEGIS	106 107 108 109 110 111 112	RCL STO STO *LBL CSE	D I I I I I I I I I I I I I I I I I I I			Ban	d Elimir	
048 049 050 051 052 053 054 055 056	ENT† X2 1 - IX + ST03 LN RCLB	12	J3 J4		106 107 108 109 110 111 112 STERS	RCL STO STO *LBL SSE STO *LBL	D II 4 4 3 19 2		,	Ban Higi	d Elimir	ation.
048 049 050 051 052 053 054 055	ENT†	2	3 Used 4	REGIS Ripple, dB	106 107 108 109 110 111 112	RCL STO STO *LBL SSE STO *LBL	D I I I I I I I I I I I I I I I I I I I		· σ	Ban Higi	d Elimir	
048 049 050 051 052 053 054 055 056	ENT† XP 1 IX + ST03 LN RCLB			Ripple, dB	106 107 108 109 110 111 112 STERS	RCL STO STO *LBL SSE STO *LBL	D I I I I I I I I I I I I I I I I I I I	Ī		Ban Higi	d Elimir	ation.
048 049 050 051 052 053 054 055 056	ENT† X2 1 - IX + ST03 LN RCLB	2 \$2	3 Used 4 S3 S4	Ripple, dB	106 107 108 109 110 111 112 STERS	RCL STO STO *LBL SSE STO *LBL	D II 4 4 3 19 2	7	$\frac{7}{\omega_0}$	Ban Higi	d Elimir	ation.
048 049 050 051 052 053 054 055 056	ENT† XP 1 1 IX + ST03 LN RCLB	S2	S3 S4	Ripple, dB	106 107 108 109 110 111 112 STERS 5 S5	RCL STO STO *LBL CSE STO *LBL	D I I I I I I I I I I I I I I I I I I I			Ban Higi	d Elimir	ation.
048 049 050 051 052 053 054 055 056	ENT† XP 1 1 IX + ST03 LN RCLB			Ripple, dB	106 107 108 109 110 111 112 STERS	RCL STO STO *LBL CSE STO *LBL	D I I I I I I I I I I I I I I I I I I I	Į,		Ban Higi	d Elimin — — — h pass.	ation.

113 GSB1		169 RTN	
114 *LBL0		170 R/S	
115 1/X			
	i i		1
117 GT05	l. =		
11E #LBL1	Low Pass		
119 RCLA			
120 RCL7			i
121 ÷			
122 GT05			
	Band Pass		
123 *LBL3	Dana - ass		
124 RCLA			
125 X2	l .		
126 RCL7	l i		
127 X2 128 -			
129 RCLA	1		1
130 ÷			
131 RCL8	1		
132 ÷	1		
133 *LBL5	l		
134 ABS			
135 STOC			
136 RTN			
137 *LBLd			
138 ST04			
139 1			
140 9	dB Ripple→ε		
141 ÷			
142 10×			
143 1			
144 -	i i		
145 TX			
146 ST06			
147 RTN	High Pass		
148 #LBLb.			
149 2			
150 GT00	Band Pass		İ
:51 ≭LB Lc	54.14 . 433		
152 3			
153 GT01	Band Elimination		
154 *LBLC	Dania Cilifiliation		
154 #LBEC 155 4			
156 *LBL1			1
157 GSB0	·		
158 R↓			
159 GSB9			ı
160 ST08			1
161 RTN	Low Pass		
162 *LBLB	2011 . 433		I
163 1			1
			1
164 *LBL0			1
165 STOD			I
166 R↓			İ
167 GSB9			
168 ST07			
	LABELS	FLAGS	SET STATUS

A R	B LP: fo	CBE: BW↑ f ₀	^D f ₁ ↑α→n	^E f₁↑α→n	O PRINT	FLAGS	TRIG	DISP
а	b HP: f ₀	CBP: BW1 fo	^d dB Ripple→ε	е	1	ON OFF 0 ☑ □	DEG ⊠	FIX 🗆
O Used	1 Used	² Used	³ Used	⁴ Used	2	1 🗆 🛭	GRAD □ RAD □	SCI □ ENG ⊠
⁵ Used	⁶ Used	⁷ Used	8	⁹ Used	3	3 🗆 😡	HAD 🗆	n_3_

Butterworth or Chebyshev Filter Design

001 *LBLE	BUTTERWORTH	057 RCL8	
902 RCLE 903 STOI	INITIALIZE counter	958 ÷ 959 \$\$86	
903 STOI 904 SF1		969 CSB5	
965 *LBL8	BEGIN loop 8.	961 LSTX	
806 RCLE		862 ÷	
907 RCLI	Butterworth equations	063 1/X	
90 8 -		964 RCL7	
009 1		965 X2	
010 +	l	966 ÷	
811 ST09	Store i	0€7 CSB6	
012 2		068 CHS 069 CTOR	
013 ×		069 GT00 070 #LBL4	Band Elimination
914 1 915 -		871 XZI	Dand Chimination
016 Pi		072 R4	
017 ×		073 RCL8	l i
018 2		074 ×	1 1
019 ÷	(2i – 1) π/2n	075 RCL7	1
020 RCLE	1	076 X2	1
021 ÷	1	077 ÷	
022 SIN		978 CSB6	
923 2		079 GSB5 080 LSTX	ł i
024 × 025 *LBL9		981 ÷	1
826 STOA		982 RCL7	1
827 RCL5		983 X2	
828 1		084 ×	
029 CHS		985 1/X	1
030 RCL9		086 CSB6	
031 CSB5	DISPLAY i	087 CHS	
032 Y*	/ A3	988 *LBL9	
833 Y×	R ^{(-1)ⁱ}	889 CSB5	
934 ×	l	090 F0? 091 SPC	1
035 RCLD 036 X#1	Branch to appropriate routine for frequency	092 F1?	150
037 CTO:	transformation.	093 CT01	IF Butterworth THEN REPEAT loop 8
038 *LBL1		094 DSZI	ELSE REPEAT loop 7.
039 X21	Low Pass	095 CT07	1 2202 1127 2711 1000 71
848 RJ	1	09€ RTN	
041 RCL7		097 *LBL1	1
042 ÷	1	098 DSZI	1
043 GSB6		099 GTO8	1
044 CT00		100 RTN	
045 *LBL2	High Pass	101 *LBL6 102 1	Subroutine to change sign of capacitors.
046 XZI 047 R↓	riigii rass	103 CHS	or capacitors.
948 RCL7	1	104 RCL9	
049 X		185 Y×	
050 1/X	1	1 0 6 ×	1
051 GSB6	1	107 RTN	
052 CHS	1	108 *LBLD	CHEBYSHEV
953 GT00	Band Ban	109 1	
054 *LBL3 055 X≠I	Band Pass	110 ST09	
056 RI		11: CF1 RCL4	
100	REGI	STERS	1
0 1 2	3 4 Ripple, dB	⁵ R ⁶ ε ⁷ ω ₀	8 BW 9 i
S0 S1 S2	S3 S4	S5 S6 S7	S8 S9
51 52	53 54	35 36 37	20 29
A G ₁ , G _{i-1} B a ₁ , a _i	C γ^2	D 1 LP 3 BP E n	counter

A B C D CH'SHEV E B'WORTH O PRINT FLAGS TRIG DISP a b c d e 1 Butterworth O SCI DEG SC FIX □ 0 Used 1 Used 2 Used 3 Used 4 Used 2 □ SCI □ C C C C C C C C C C C C C C C C C C C	113 4 114 8 115 ÷ 116 1 117 ex 118 LOG 119 ÷ 120 ENT1 121 + 122 e 123 1 124 X=Y 125 + 126 LSTX 127 1 128 - 130 RCLE 131 STDI 132 2 133 X X 134 1 X 135 Y* 136 ENT1 137 1 X 138 - 136 ENT1 141 X 152 Y* 146 RCLE 147 SIN 148 SIN 149 STDB 150 RCLE 151 X 152 RCLC 153 IX 154 ÷ 155 RCLE 157 RCLB 158 RCLE 159 RCLI 160 - 161 1 162 + 163 STD9 164 1 165 - 166 2 167 X 168 1	Chebyshev setup BEGIN loop 7. Chebyshev equations	165 177 172 173 174 175 176 177 177 178 188 188 188 198 191 191 192 193 194 195 195 197 198 199 199 199 199 199 199 199 199 199	Pi		DISPLAY I IF flag 0 THEN PRII ELSE DISPLA	NT
a b c d e l Butterworth 0 N OFF 0 N O	A B C	10	E B'WORTH				
0 Used 1 Used 2 Used 3 Used 4 Used 2 1 □ EG 52 FIX □ C GRAD □ SCI □ C C C C C C C C C C C C C C C C C C		Chanev	BWONIN			TRIG	DISP
0 Used	a b c	d	e	¹ Butterworth	ON OFF	DEG ₽	FIX 🗆
5 DISPLAY 5 Used 7 Loop 8 Loop 9 Used 3 3 80 n 3	Osed Osed Os	0 0560	0	3	1 🗆 🗓 2 🗆 🕄	GRAD □	SCI □ ENG_EX

Bode Plot of Butterworth and Chebyshev Filters

881	*LBLc						857	RCLE			
882	1						0 58	STOI		1	
883	9			Conv	ert dB rip	ple to ϵ .	859	GSB7		Cor	mpute ω _N
004	÷							*LBL8			
005	19×						861	RAD		BE	GIN loop 8.
88€	1						862	GSB€		Co.	mpute s _k
887								RCL1		00	iipute sk
998	18						863				
889	ST0€						864	RCL9		1	
				Store	ϵ		865	+			
810	R↓						96€	RCL2			
811	CFE			Cheby	/shev		867	→P			
012	STOE			Store	n		868	ST÷4		Gai	n .
813	RTN						969	X2Y			
814	*LBLA						878	ST-5		Pha	ise
815	SF@			Rutto	rworth		671	RCL2			
01€	STOE			Store			8 72	RCL1			
817	RTN			Store			873	→P			
818											
819	2				_		874	ST×4		Gai	in normalization
				High			875	→R			
828	ST00			-			87€	RCL9			
821	#LBLc						e77	+			
822	3			Band	Pass		878	RCL2			
823	ST01			-			879	→P			
824	*LELC						986	XΣ			l
825	4			Rand	Eliminat	ion	6 81	X≢Y		1	
82€	*LBL1			Dania		1011	882	R.J		1	
827	SSB0			C+	£:14 l					1	
828	R↓					aracteristic	883	÷		l	
829	SSB.			and a	0 ·		884	ST+3			ne delay
				_	_		985	DSZI			IILE counter ≠ 0
636	ST08				$2\pi \times BW$		88€	ST08		RE	PEAT loop 8.
831	RTN			-			8 87	RCLA		1	
832							889	1		1	
633	1			Low F	Pass		989	esb9			
834	#LBL0						698	÷		Fre	quency
835	STOD			Store	filter cha	aracteristic.	891	RCL4		1	
836	R↓						892	LDG		- 1	
037	esb9			Multi	oly by 27	,	893	2		- 1	
838	ST07			Store			894	ē		1	
839	RTN						895	x		1	
848							89€	RND		C=	n, dB
841	STOR			•			897	RCL5		Gai	n, ab
842	SSB9			Store	Δ†		898				
				_				1			
843				Store	$\Delta\omega$		899	→₽		- 1	ļ
844	R↓						100	DEC		- 1	
845							101	→P		Pha	ise, degrees
84€				Store	ω_2		102	CTX		- 1	
847							103	RCL3		Del	ay I
848							184	PRST			nt f, H , θ, t
849	STOA			Store	ω_1		195	RCLE		'	
858	RTN				· ·		18€	RCLA		- 1	
851				Initial	ize regist	ers	107	F10		IF 6	flag 1
6 52							198	STOP			EN GO TO LBL 0
853							109	RCLC		ELS	
6 54							110	+			ω←ω + Δω
855							111	ET03		Ι '	~ ~
856							112	*LBL8			
# # # # # # # # # # # # # # # # # # #	3104					DEC	STERS	+2020			
0 4,	Is .		2 , .	3 ,				16	17	18 _	9
^U ∆f	' -Im{	s _k }	² -Re {s _k }	ď de	lay	⁴ –Π Η(ω)	$^{5}\Sigma\theta$ (ω)	ϵ	′ω₀	В	$W = \omega_N$
S0	S1 `	<u> </u>	S2 ,	S3		S4	S5	S6	S7	S8	S9
1	Ĭ.							1			
Α	-	В			С	Δω	D 1 LP	3 BP	E n		I
ω_1, ω		1	ω_2			Δω		4 BE	1 "		counter

113 RCL0		169 LSTX			
114 ×	ω←ω x Δf	170 CHS		1	
115 #LBL3	1	171 e ^x			
116 STOA	Store new ω	172 +		1	
117 X≟Y?	IF $\omega \leq \omega_2$	173 ENT†		1	
118 GTOE	THEN REPEAT loop E	174 ENT†		l	
119 RTN	ELSE stop.	175 LSTX		1	
120 #LBLT		176 2		i	
121 RCLD	Subroutine to compute ω _N .			ł	
122 %≇I		178 -		ł	
123 GTO:	GO TO case i.	179 STx2		1	
124 *LBL4	BE	180 R↓		l	
125 GSB3		181 ST×1		ł	
12€ GT00		182 2		ł	
127 *LBL2	HP	183 ST÷2		ľ	
128 GSB1		184 ST÷1		1	
129 *LBL0		185 RTN			
130 1/X	1	186 #LBL1		Subroutine	to compute
131 CHS	1	187 RCLI		Butterwort	
132 GT05	1	188 2		location.	
133 *LBL1	LP	189 x		1	
134 XZI		198 1		1	
135 RCLA		191 -		1	
136 RCL7	1	192 RCLE		1	
137 ÷	1	197 ÷			
13E GT05		194 GSB9		1	
139 *LBL3	BP	195 4			
146 XZI	BP	19€ ÷			
141 RCLA		197 1			
141 KCLH 142 X2		198 →₽			
	i	199 ST01			
143 RCL7		280 XZY		l	
144 X2 145 -		201 5702		1	
		282 RTN			
146 RCLA 147 ÷		203 #LBLd			
		204 1		i	
148 RCL8		205 F10			
	1	206 CLX		l	
150 *LBL5				Set logarith	nmic
151 ST09	Store ω _N	207 SF1 208 X=0°		increment.	
152 RTN					
153 *LBL6	Subroutine to compute s _k . IF Butterworth				
154 FØ?	THEN GO TO LBL 1	218 RTH		Set linear in	
155 GTO:	ELSE get Butterworth pole	211 *LBL9		1	
156 GSB1	and modify it.	212 2			to multiply
157 1	and modify it.	213 ×		by 2π.	
158 RCL6	1	214 Pi		I	
159 1/X	1	215 ×		l	
160 →P	1	216 RTN		1	
161 XZY	1	217 R/S		l	
162 R÷	1			l	
163 LSTX	1			l	
164 +	1				
165 LN	1			l	
166 RCLE	1			l	
167 ÷	1			l	
168 e*	1	L	,	L	
A . In In	LABELS	FLAGS		SET STATUS	
A B'WORTH n B LP: f₀ C BE	: BW↑f ₀ D f ₁ ↑f ₂ ↑∆f E "	PLOT" ⁰ B'WORTH	FLAGS	TRIG	DISP
aCHEBn1dBR b HP: fo C BF	: BW↑f ₀ d LIN – LOG e	¹ LOG	ON OFF	DEG 🗆	FIX 🐷
⁰ Used	ed ³ Used ⁴ U	lsed ²	1 🗵 🗆	GRAD □ RAD ko	SCI □
⁵ Used ⁶ Used ⁷ Us	ed ⁸ Loop ⁹ U	sed ³	3 🗆 🛣	HAU K	ENG □ n <u>3</u>

Resistive Attenuator Design

											-		
001	*LBL6			_		e 57	×				l		
992	ST01		Store	Rin		95 8	-				l		
883	RTH					65 9	CHS				l		
884	*LBTB		_	_		969	ST05				l		
005	STO2		Store I	Hout		861	1				l		
99€	RTN					862	RCL4				l		
007	*LBLC					063	+				l		
908	RCL1	1				864	LSTX				l		
809	RCL2					865	1				l		
010	÷		_			866	-				l		
011	ENT?		Comp	ıte min	loss.	9€7	÷				l		
012	ENT ↑					968	RCL2						
613	1					069	×				l		
614	-					870	RCL7				l		
015	1X					071	-				l		
€16	XZY					872	ST06				ł		
017	1.8					673	ET01						
018	+					874	*LBLE				II c	alculatio	on
919	Χs					875	RCL3				ı		
826	L06	I				87€	X>Y?						> desired loss
821	1	l				€77	GT09					ENERR	OR
822	e	l				678	XZY				ELS		
823	X	I				879	1				1 9	Compute	R_1, R_2, R_3
824	GSB5	1				986	е				l		
625	STO3	ı				881	÷				1		
826	RTN	ı				882	10'				1		
627	*LBLD	l	T calc	ulation		683	ST04				1		
828	RCL3	I				6 84	1/8				l		
629	X>Y?				desired loss	885	RCL1				1		
030	GT09	1		ERROF	₹	88€	x						
031	X * /		ELSE			6 87	RCL2				l		
8 32	1	1	Con	npute R	1, R ₂ , R ₃	986	X				l		
833	0	l				989	1%				ı		
€34	÷	l				89€	RCL4				1		
835	10×	i				891	1				l		
₽3€	ST04					892	-				1		
03 7	RCL1	I				093	×				l		
938	×	I				6 94	2				ı		
839	RCL2					895	÷				1		
948	×					69€	ST07				l		
041	1X					897	1				l		
842	2					698	RCL4				1		
943	X					899	+				1		
844	RCL4	I				100	LSTX						
845	_1	I				101	1						
946	÷	1				182	- ÷				1		
847 848	ST07	I				193 194	RCL1				1		
045	5107					105	KUL1				1		
050	RCL4					106	RCL7				1		
65 1	+	l				107	1/8				1		
85 2	LSTX					108	400				1		
857	1					100	1/8						
05 3 05 4	-*					110	ST05						
85 5	÷	l				111	1						
85 €	RCL1					112	RCL4						
					REGI	STERS							
0	1 R _{in}	2 R _{out}	3 min	loss	4 N	⁵ R ₁	6 R ₂		7	R ₃	8		9
SO	S1	S2	S3	. 555	S4		-		S7	3	100		60
30	31	52	153		54	S5	S6		S7		S8		S9
4	I B			C	L	D	1	E	L			I.	
ľ	ľ		ľ	•				ľ				ľ	
												1	

115	DISPLAY IF flag 0 THEN PF ELSE DISPL	.AY.		FLAGS		SET STATUS	
A R _{in} B R _{out} C→m	in loss D	Used	Used	O PRINT	FLAGS	TRIG	DISP
a b c	d			1	ON OFF		
	3			2	0 X 🗆 1 🗆 X	DEG 😨 GRAD 🗆	FIX □ SCI □
0 1 Used 2 5 DISPLAY 6 7	8			3	2 🗷	RAD 🗆	ENG K

Smith Chart Conversions

901 #LBLc	ρ→R	L.	65 7	RTN			
992 1/X				*LBL?		Input: L	_
003 #LBLa			85 9	ENTT		Input: Z	
004 LOG			960	R↓		l k	
005 2	σ→S\	VH	861	R.		1 "	
99€ €			862	÷₽		1	
007 ×	- 1		663	R†		Subroutine	to compute
80E RTN			864	-			
009 *LBLC	R. L.	$\rightarrow \rho$	065	570€		a∠a+	k ∠ 0
ele CHS			06€	R1		a∠a-	k∠0
611 *LBLA			867	₽ŧ			
012 2	i		868	+			
013 0	1		665	+_			
014 ÷	SWR-	→ σ	878	→F			
815 18°			671	₽÷			
016 RTH			072	RCL€			
817 *LBL&	ł		8 73	→P		1	
018 1/X	$\sigma \rightarrow \rho$		874	₽↓			
019 CHS			875	XZY		1	
828 #LBLB			876	R†			
621 1			877	÷		1	
622 %≇Y	1		0 78	R4		1	
623 +			879	-		1	
824 1	$\rho \rightarrow \sigma$		686	R*		Output: ar	ng
025 LSTX	1		881	RTN		m	ag
82€ -	ł		682	R/S			
827 ÷			I				
028 RTH	1		1			1	
829 #LBLd			1			1	
030 ST01	Store	Z_0	1			1	
031 RTH			1			1	
032 *LBLD	Γ→Z		1				
833 :			1				
034 GSB7			1			1	
035 RCL1			ł			1	
8 3€ CHS 83 7 ×			1			1	
037 ×	1		1			l	
63€ →R	1		1			l	
839 →P	1		l				
840 GT09			l			1	
04: *LBLE	Z→Γ		1				
042 RCL1			1				
843 CHS						1	
044 GSB7	-		1				
845 *LBL9	Print	results	1				
846 X7Y			I			1	
647 GSB5			1				
848 XZY	1		1			1	
049 GSB5			1			1	
ese RTN			1			1	
851 #LBL5	Print	routine	1			1	
852 F8?			1				
853 PRTX			1				
854 F8?			1				
055 RTN			1				
						1	
0 1 -	2 3	REGI	STERS 5	6	7	8	9
0 Z ₀	ľ ľ	ľ	ľ	Used	ľ	ľ	,
S0 S1	S2 S3	S4	S5	S6	S7	S8	S9
A	В	С	D		E	ı	

1								
ł								
				İ				
1				- 1				
1								
		- 1						
	To	LAI	BELS		FLAGS		SET STATUS	
A SWR→σ	^B ρ→σ	C R.L.→ρ	D L→Z	E Z→Γ e	O PRINT	FLAGS ON OFF	TRIG	DISP
a σ→SWR	b σ→ρ	^C ρ→R.L.	^d Z ₀	4	 2	0 🗷 🗆	DEG ☑ GRAD □ RAD □	FIX kū SCI □
5 DISPLAY	6	⁷ Used	8	9 Used	 3	FLAGS ON OFF 0 & 1 2 3	RAD 🗆	FIX & SCI DENG DENG DENG DENG DENG DENG DENG DENG
		Joseph	L		 	ં ા હ		.,

Transmission Line Impedance

881	*LBLA				e 57	7			
802	STOR		Open two-wire lin	ne.	958	6			
803	R.J				95 9	×			
884	÷				969	RCL0			
805	2				861	1.7			
88€	×				9€2	+			
887	ĹN				863	ST85		l	
					864	*LBLD		Wires in	parallel near
889	1				865	5700		ground.	
009	2							ground	
610	0				866	R.J		l	
811	×				867	ST01		1	
0 12	RCL@				868	£1		1	
613	1X				0€9	ST02			
614	÷				876	R↓			
815	GT05				871	ST03		l	
81€	*LBLB		Single wire near g	round.	6 72	RCL1		1	
e17	STOR				873	÷		l	
e18	R.				0 74	1/8		l	
819	4		l		875	2		1	
					87€	x		1	
828	¥		l		877	χ̂ε		1	
021	÷				877 878	۸.		1	
822	178		l					ł	
023	FDE				8 79	+		1	
824	1		ļ		e ee	1%		ł	
025	3				681	RCL1		Į.	
82€	8		ì		682	X		l	
827	×				8 83	RCL2		l	
828	RCL@				884	÷		I	
829	1%				085	4		1	
829 838	÷				68€	x		I	
631	6T05				887	LOG		1	
832	*LBLC				888	€		i	
633	STOR		Balanced wires no	ear	089	و		1	
e 34	R.		ground.		898	x		1	
835	STO1		*		e 91	RCLO		1	
83€	R.‡		1		e 92	1%			
837	ST02		1		093	***			
	R4				894	GT05		1	
638			1		895	*LBLE		C	
639	ST03							Coaxial	line
848	RCL1		İ		89€	ST00			
641	÷		ļ		897	₽↓		l	
842	2		1		698	÷			
043	÷		l		899	LN.		1	
844	Χs		1		10€	€		1	
045	1				101	e		1	
846	+		l		102	X		1	
847	1%				103	RCL0		1	
848	1/X				184	12.		l	
849	2				105	÷			
6 50	×				10€	*LBL5		DISPLA	AY ROUTINE
951	RCL3				107	FB?		IF flag	
85 2	×				108	PRTX		THEN	PRINT
853	RCL2				189	RTN		ELSE	
854	÷		1		110	R/S		DIS	PLAY.
855	LOG		l		۰٬۰۰۱	P . U			
95€	2		1						
	<u> </u>			REGIS	STERS				
636		To	3 4		5	6	7	8	9
0	1 .	2							
0 ε _r	1 h	d	D						
0	1 h	g d	D S3 S4	ı	S5	S6	S7	S8	S9
0 ε _r	S1	d	S3 S4					S8	S9
0 ε _r		d	D	1	S5	S6		S8	S9

				-
				-
				- 1
	1			
	LABELS	FLAGS	SET STATUS	
//////	LABELS C P D P F	O PRINT	FLAGS TRIG DISP	
a b	c d e	O PRINT	FLAGS TRIG DISP	
a b	LABELS C	O PRINT	FLAGS TRIG DISP	

Microstrip Transmission Line Calculations

	*LBLn				05 7	RCL 8		l	
002	SF1				8 5€	+			
983	STO7		Store h		8 59	2		l	
884	XZY				666	P:		l	
995	ST0€		Store w		9€1	x			
996	SFØ				862	XZY			
887	X2 Y?		IF w > h		863	÷			
800	CFØ		THEN cle	ar flag O	064	GT02			
889	÷				965	*LBL1		Compute	Z ₀ for w ≤ h.
010	ST09		Store h/w		86€	8		1	-
811	1/8				867	RCL8			
612	STOE		Store w/h		968	÷			
e13	1		1 01010 11711		869	LSTX			
814	ė				876	4			
815	LN				871	÷			
81€	STOR			•	872				
817			Store In 1	U	873	LH		ł	
	RTH				874	#LBL2		ł	
	*LBLB		1		875				
819	1		ı			6		1	
626	XZY		1		87€	, e		I	
821	+		1.		877	CTOA		l	
822	LSTX		Compute	€eff	878	STOA		Store Z ₀	
823	1		1		879	X		1	
824	-		1		989	ST01		Store Z _c	
825	1				081	XZY		į .	
826	0				082	PRTX		Print v _r	
827	RCL8				683	XZY		1	
928	÷				084	PRTX		Print Z _c	
829	1				885	RTH			
936	+				€86	*LBLD		IF uniforn	n assumption
631	1X				827	1X		THEN GO	TO 1.
832	÷				989	F1?		I	1
833	+				889	GT01		1	
834	2		1		898	#LBL4		i	1
835	÷		1		891	RCL4		1	
83€	īχ		ı		092	X		1	
637	1/8		1		693	RCL7		l	
838	ST02		Store v _r		894	÷		i	
839	F8?		IF w ≤ h		895	2		l	
848	GT01		THEN GO	TO 1	896	×		ı	
			1	, 10 1.	697	P;		l	
841	DCI O		1		698	× ×		1	
842 843	RCL9		1		699	ST03		Store part	ial result
844	6		1.		190	RTH		Store part	ai iesuit.
	γ×		Compute	Z_0 for w $>$ h		#LBL1		l	
845 846	1"		1		181			I	
847	4		1		102 103	2 8		1	
			1					I	
848	ACL O		ı		104	RCLB		1	
849	RCL8		ı		185	÷		I	
656	-		1		106	RCL9		1	
851 853	-,		-		107	X DOLA		ı	
852	2		I		108	RCLA		I	
853	:		I		109	÷ .		I	
854	4		1		118	ST04		I	
0 55	2		1		111	R↓			
056	+				112	ST04		1	
					STERS				_
⁰ In 10	1 Z _c	2 Vr	3 α _c	4 A	⁵ f/10 ⁹	6 w	⁷ h	8 w/h	9 h/w
1		S2	S3	S4		S6	S7	S8	
S0	S1	S2	53	P4	S5	36	57	198	S9
<u> </u>		TB	<u> </u>		D		- -		
^ z _o		ľ	С		ľ		E	ľ	
1		ı	1		ı		ı	1	

113 #LBLE]	169 1	
114 EEX	I	176 +	
115 9	I	171 FØ?	lFw≤h
	1	172 GTO:	THEN GO TO 1.
11€ ÷	ł	173 1	
117 ST05	l		
118 1%		174 RCL9	
119 RCL3	1	175 -	Compute A for w > h.
120 ×	Print α _c	176 5	
		177 Y	1
121 RCL2		178 6	ł
122 ÷			
123 STOB			1
124 PRTX		180 .	l
125 LSTX		181 4	
		192 4	
		183 +	
127 2	l	184 RCL9	
128 ×	Print R		
129 RCL4 138 ÷		185 X2	
130 ÷		18€ ×	
131 RCL9	1	187 1	
132 ×	i	188 +	l l
	I	189 x	l
133 PRTX	I		1
134 2	I	190 RCLA	l
135 Pi		191 ×	1
136 ×	I	192 7	l
137 RCL0		193 2	
138 ÷		194 €	
		195 ÷	
139 RCL5			1
140 ×		196 P:	
141 3		197 GTD0	
142 ÷	Print Q ₀	198 *LBL1	Compute A for w ≤ h.
143 RCL2	1	199 3	Compute A for W & III.
	1	200 2	
144 ÷			
145 RCLB	İ		
146 ÷		202 X2	
147 PRTX		283 ×	l i
14E RTN		204 1	1
149 *LBLC	ł	205 -	
	1	20€ ×	1
150 CF1	1		
151 RCL7		207 RCLA	
152 2 153 x	1 ,	208 ÷	l
153 x	Calculate $\frac{\partial w}{\partial t}$	2 8 9 LSTX	
154 XZY	ðt .	21€ €	
155 ÷	I	211 0	1
156 RCL8	I	212 ÷	l l
	1		
157 Pi	1	213 e*	
158 2	1	214 ÷	
159 ×	l	215 .	
160 ×	i	216 4	l
161 ×	I	217 #LBL0	
162 X>Y?	l	218 ÷	
	1		1
163 XZY	l	219 RCL0	l l
164 LH	ŀ	220 ÷	1
165 Pi	l	221 Fi	
166 ÷	l	222 ÷	
167 RCL8	l	223 5704	Store A
168 +	l	224 RTH	
.66 7	LABELS		CET CTATUS
A wth B s V Zo C t		D = 10 > 1	SET STATUS
VIII CF 17, 20 1	·A P 1	$\rightarrow \alpha_{c}, R, Q_{0}$ w > h FLAGS	TRIG DISP
a b c	d e	1 uniform ON OFF 0 □ 🗵	DEG 😡 FIX 🗆
O Used 1 Used 2 U	sed 3 4 U	Jsed ² 1 🗆 🗷	GRAD □ SCI □
5 6 7	8 9	3 2 2	RAD □ ENG 図 n 3

Transmission Line Calculations

00: #LBLa		9 57 RCL6		
96 2 EEX		9 58 +		
003 1		859 ST04		
884 8		960 RCL6		
005 ÷		061 RCL8		
	Store f/10 ¹⁰			
00€ STD9	Store 1/10	002		
997 2		8 €3 ST02		
008 F;		864 RCL5		
009 ×		065 RCL3		
010 ×		96 € ÷		
011 STO8	Store ω'	867 ST×1		
012 RTH		068 RCL5		
013 #LBLA	0. 0	869 RCL3		
014 ST01	Store R ₀	070 ×		
015 % ± Y		071 ST×7		
81 € ST 0 2	Store v _r	072 RTH		
017 RTH		073 *LELD		
			1	
018 *LBLP	Store &	874 X⊋Y	1	C+
019 STOA	-	075 ST08		Store α _D
820 2		07€ R↓		_
821 ×		077 ST03		Store α _C
62 2 3		078 RCLA		
023 RCL2		079 RCL2		
024 ×		ese RCL9		
	Store 3 v _r			
025 ST03	313.3 3 17	081 Pi	1	
<i>82€</i> ÷		082 X		
027 ST07	Store 21/3 v _r	083 1		
828 RTH		B 84 .		
829 *LBLC		085 5		
030 RCL3		98€ ÷		
		987 X≇Y		
031 ×				
032 RCL1 033 ÷				
		0 89 ST0€		
034 ST05	Store 3 v _r R/R ₀	090 ×		
035 R↓		091 2		
036 RCL1		89 2 ×		
037 ×		093 ST07	1	
036 ST×3	$R_3 \leftarrow 3 v_r R_0 G$	094 RCL8		
	113 5 47 118 4			
039 RCL8		895 1		
040 RCL5		89€ 6		
841 →P		897 LN		
842 IX		69 8 2		
043 ST05		099 0		
044 X2Y		100 ÷		
		101 RCL6		
045 2 046 ÷		102 ÷		
047 ST06		103 ST×3		
			1	
045 RCLB		104 ST×8	l	
04: RCL3		105 RCL8		
6 56 →P		10€ RCL3	1	
651 1X		107 -	1	
052 ST03		108 ENT?	1	
€53 X≇Y		109 ST05	1	
954 °		110 RCL8	1	
854 2 855 ÷				
85€ STO8		111 3		
656 5198		112 x		
L		STERS		
$\begin{bmatrix} 1 & R_0, Z_0 & V_r \end{bmatrix}$	3 Used 4 Used	⁵ Used G Used	⁷ 2ℓ/3 v _r ,2β ₀ ℓ	${}^{8}\omega'$, ${}^{8}D$ 9 f/10 10
S0 S1 S2	S3 S4	S5 S6	S7	S8 S9
	1 1	l I	1	1 1
A 0 B	C	D	E	Tı Tı
A R	c	D	E	

113 RCL3 114 + 115 × 116 2 117 ÷ 118 CHS 119 1 120 + 121 +P 122 STX1 123 XXY 124 ST02 125 RCL5 126 X2 127		169 CHS 178 X 171 XIY 172 CHS 173 X2Y 174 +R 175 1 176 + 177 +P 178 RCL7 175 X 181 X2Y 182 RCL8 185 - 184 CHS 185 +R 187 1 188 - 189 +P 198 1/X 191 2		
116 2 117 ÷ 118 CHS 119 1 1200 + 121 +P 121 +P 122 STX1 123 XZY 124 ST02 125 RCL5 126 X0 127 2 128 ÷ 129 1 130 + 131 RCL3 132 RCL8 133 + 134 +P	Store Z _L Store θ _L	1773		DISPLAY ROUTINE IF flag 0 THEN PRINT ELSE DISPLAY.
168 2	LABELC	FLAGS		T STATUS
A v _r ↑R ₀ B ℓ C G	tr D_{α_D} tr E Z	L→Z _{in} PRINT	FLAGS	T STATUS TRIG DISP
a f b c	d e	1	ON OFF	
1	3 4	2	0 K 🗆	DEG 🖫 FIX 🗆
			1	GRAD □ SCI □ RAD □ ENG █
⁵ DISPLAY ⁶	8 9	3	3 🗆 🗵	n_3_

Unilateral Design: Figure of Merit, Maximum Unilateral Gain, Gain Circles

001	*LBLA					65 7	+				
992	2					€ 58	RCLD				
883	×					8 59	Χż				
884	2	J				860	CHS				
005	1		Input [S	i]		861	GSB1				
80€	_*					862	GSB2				
807	STOI	1					ESB5			Display (3- max
						963					
399	R↓	1				86 4	RTH			DISBLAS	Y ROUTINE
869	STO:					86 5	*LBL5			IF flag 0	ROUTINE
0 10	RTH					9 66	F8?				NAT
011	*LBLE					967	PRTX			THEN P	TINI
812	RCL1		Compu	te		96 8	FB?				
813	RCL3		u, G _u , 0	G _{min} , G _{max}		86 9	RTH			ELSE	
814	x	1	Go. Ga	max, G _{2max} .		878	R/S			DISPL	₋AY.
815	RCLB	l	-0, -1	max, Times		071	RTH				
816	X					872	*LBL1			Subrouti	ne to compute
	RCLD					873					
017						873 874	+1			1	
818	×.	l								1 + x	
0 19	1	l				075	1/X			1 + X	
929	RCL1					€76	RTH			Cubacci	
921	Χz					677	*LBL3				ne to re-compute
822	-					6 78	RCLB			G _u .	
823	1	I				879	Χž				
624	RCLD					986	RCL€			l	
	72 72	ı				881	÷				
825 826	2"					882	*LBL2			Subrouti	ne to convert to
827	×					883	LOS			decibels.	
828	STO6					884	1				
						885	ė			1	
829	÷									ĺ	
9 30	ST07		-			98€	×			1	
631	ese5		Display	u		087	RTN				
032	esb3	- 1				889	*LBL4			Subrouti	ne to compute
83 3	GSB5		Display	Gu		989	1				
834	RCL?					0 90	+			1 (1 + x	
835	SSB4					89 1	Χs			(1 + v	12
83€	GSB2	i				89 2	1/8			'''^	,
637	ESB3					893	RTN				
638	+					894	*LBLC			Compute	Te1 . 0e1
039	GSB5		Display	G .		895	1				.017701
846	RCL7	1	Display	Omin		896	6T06			1	
841	CHS					897	#LBLc			Compute	
	ESB4	1				898	2			Compute	102, 202
842		1								l	
843	CSB2					89 9	3				
844	ese3	1				100	*LBL6			l	
045	CCDE					161	STOI			l	
046	£SB5		Display	G _{max}		102	X27			l	
847	RCLB					103	1			I	
848	Χs					104	8			l	
849	GSB2					105	÷			I	
6 50	ese5		Display	G _o		10€	10×			l	
951 952	RCL 1					107	ST00			I	
						108	RCL:			I	
05 3	CHS	1				109	×			1	
6 54	es e 1					110	LSTX			l	
85 5	CSB2					111	Χs			l	
85 6	CSB5		Display	G _{1 max}		112	RCLE			l	
				- , viiun	BECH	TERS	RULE			L	
0	Ī1	2	3	14	neul	c	6 ,	. 7		8	9
Used	` \$ ₁₁		S ₁₂	<u> </u>		G _i	s ₂₁ ² /		u	r	ρ
S0	S1	S2	S3	S4		S5	S6	S7		S8	S9
A	IB					D	1	L L		1 .	
ľ	ا	S ₂₁	۲			S ₂ :		ľ		ľ	pointer

118 119 128 121 122 123	X 1 + + + CSB5 STOB LSTX 1 RCL1 RCL1 RCL2	Display	<i>(</i>					
132 137 134 135	SSBS STD9 RTM R/S							
		LAB	ELS		FLAGS		SET STATUS	
^A s _{ij} †ij	B Compute	$^{\text{C}}$ $G_1 \rightarrow r_{o1}, \rho_{o1}$	D	E	O PRINT	FLAGS	TRIG	DISP
	b		d	e	1	ON OFF		
		-2 .02#-02				ON OFF	DEG 🖬	FIX 🐷
0	¹ Used	² Used	3 Used	4 Used	2	1 🗆 KO	GRAD □	SCI ENG P
5 Used	⁶ Used	7	8	9	3	2 K 3 K	RAD 🗆	n_2
		L						

Bilateral Design: Stability Factor, Maximum Gain, Optimum Matching

00: #LBLA		8 57 X 2 Y	
902 2	l	0 58 ST07	Store ∠ ∆
			0.0.0.2.2
96 3 ×	Compute pointer	e 59 RCLD	1
964 2 865 1		960 RCL1	
1 885 1			
88€ -		0 €1 GSB7	1
		062 RCL6	
007 STOI		863 X2	
888 R↓			1
	l	0 64 1	
009 STO:	Store s _{ij}	<i>06</i> 5 +	
010 ISZI			
011 R4			
		967 X2	
012 STO:	Store θ_{ij}	96 8 -	
013 RTN			
		0€ 9 RCLD	
014 *LBLB		970 X2	
015 RCL2		0 71 -	
016 RCLE	Compute K, G _{max}		
	Compute K, G _{max}	0 72 2	
817 +		073 ÷	
018 1			
		074 RCL3	
		075 RCLB	
020 RCL1		0 76 ×	
021 RCLD			
		077 ABS 078 ÷	1
82 2 ×		0 78 ÷	1
82 3 ×		0 79 ST09	1
824 X⊋Y			1
		080 GSB5	Display K
025 LSTX		0B1 ENT†	
026 ×		08 2 ×	
827 RCL3		083 LSTX	
028 RCLB		0 84 XZY	
82 9 ×		085 1	
		88 6 -	
831 CLX		887 JX	
032 RCL4			1
032 8024		088 RCL5	1
033 RCLC 034 +		0 89 ×	
034 +		090 CH S	
035 RCL9		0 91 +	
03€ ST07		092 RCLB	1
			1
			1
83 8 1		0 93 x	1
			1
		094 RCL3	
039 →R		094 RCL3 095 ÷	
039 →R 040 ST06		094 RCL3 095 ÷ 096 ABS	
039 →R		094 RCL3 095 ÷ 096 ABS	
039 →R 040 ST06 041 R4		094 RCL3 095 ÷ 096 ABS 097 LOG	
039 →R 040 ST06 041 R4 042 RCL7		094 RCL3 095 ÷ 096 ABS 097 LOG 098 1	
039 →R 048 ST06 041 R4 042 RCL7 043 ×		094 RCL3 095 ÷ 096 ABS 097 LOG 098 1	
039 →R 040 ST06 041 R4 042 RCL7		094 RCL3 095 & 096 AB 097 LOG 098 1	
039 →R 040 ST06 041 R4 042 RCL7 043 x 044 LSTX		094 RCL3 095 + 096 ABS 097 LOG 098 1 099 0 100 ×	
039 →R 048 STO6 041 R4 842 RCL7 043 X 044 LSTX 045 STX6		894 RCL3 895 ± 895 ABS 897 LOG 898 1 895 6 1868 × 181 CSB5	Display G _{max}
### 839 ### 848 \$706 ### 842 ### 842 ### 844		094 RCL3 095 ABS 097 LOG 098 1 099 0 100 X 101 GSB5 162 RTN	Display G _{max}
039 →R 048 STO6 041 R4 842 RCL7 043 X 044 LSTX 045 STX6		094 RCL3 095 = 096 ABS 097 LOG 098 1 099 8 100 × 101 GSB5 102 RTH 183 #LBLc	
839 → R 848 STD6 841 R4 842 RCL7 843 × 844 LSTX 845 STX6 846 CLX 847 RCLE		094 RCL3 095 = 096 ABS 097 LOG 098 1 099 8 100 × 101 GSB5 102 RTH 183 #LBLc	
039 →R 048 STO6 041 R4 042 RCL7 043 X 044 LSTX 045 STX6 046 CLX 047 RCL6 048 R4		894 RCL3 895 ABS 897 LOG 898 1 899 0 180 SB5 181 GSB5 182 RTH 183 #LBL0 184 RCL7	
039		094 RCL3 095 ABS 097 LOG 098 I 099 0 100 CSB5 101 CSB5 102 RTH 103 #LBL0 104 RCL7 105 RCL6	
039		894 RCL3 895 = 1 896 ABS 897 L06 898 1 899 8 180 × 181 GSB5 182 RTM 183 **LBLc 184 RCL7 185 RCL6	
039		894 RCL3 895 = 1 896 ABS 897 L06 898 1 899 8 180 × 181 GSB5 182 RTM 183 **LBLc 184 RCL7 185 RCL6	
039		894 RCL3 895 ABS 897 LOG 898 1 899 0 180 SB5 182 RTH 183 #LBL0 184 RCL7 185 RCL6 186 RCLD 187 RCLE	
839		094 RCL3 095 ABS 097 LOG 098 1 099 0 100 x 101 GSB5 102 RTN 103 *LBL0 104 RCL7 105 RCL6 106 RCLD 107 RCLE	
039		894 RCL3 895 ABS 897 LOG 898 1 899 0 180 SB5 182 RTH 183 #LBL0 184 RCL7 185 RCL6 186 RCLD 187 RCLE	
839		894 RCL3 895 4 896 ABS 897 LOG 898 6 180 8 181 GSB5 182 RTM 183 **LBLc 184 RCL7 185 RCLG 186 RCLD 187 RCLG	
039		894 RCL3 895 ABS 897 LOG 898 1 899 0 180 SB5 182 RTH 183 #LBL0 184 RCL7 185 RCL6 186 RCLD 187 RCLE 188 CHS 189 GSE9 110 CHS	
039		894 RCL3 895 = 8 896 ABS 897 LOG 898 1 899 8 181 GSB5 182 RTM 183 **LBLc 184 RCL7 185 RCLG 186 RCLD 187 RCLE 188 CHS 189 GSB9 110 CHS	
039	Store ∣∆∣	894 RCL3 895 ABS 897 LOG 899 D 180 SSE5 181 GSE5 182 RTN 183 *LBLc 184 RCL7 185 RCL6 186 RCLD 187 RCLE 188 CHS 189 CHS 110 CHS 111 CHS	
039	Store ∣∆∣ REGIS	894 RCL3 895 ABS 897 LOG 899 D 180 SSE5 181 GSE5 182 RTN 183 *LBLc 184 RCL7 185 RCL6 186 RCLD 187 RCLE 188 CHS 189 CHS 110 CHS 111 CHS	
039	REGIS	894 RCL3 895 4 896 ABS 897 L0G 899 1 809 8 1801 GSB5 1802 RTH 1803 #LBL0 184 RCL7 185 RCL6 186 RCLD 187 RCLE 188 CHS 189 CHS 189 CHS 189 CHS 189 CHS 189 CHS 189 CHS 189 CHS 189 CHS 189 CHS 189 CHS 111 RCL2 112 RCL1	Compute Γ_{ms}
039 +R 048 ST06 041 R4 042 RCL7 043 X 044 LSTN 045 STN6 046 CLX 047 RCL6 048 R4 049 -	REGIS	894 RCL3 895 4 896 ABS 897 LOG 898 1 899 8 180: GSB5 182 RTN 183 #LBL0 184 RCL7 185 RCL6 186 RCLD 187 RCLE 188 CHS 189 GSB9 110 CHS 111 RCL2 112 RCL1	Compute Γ _{ms}
039	REGIS 3 s ₁₂ 4 θ ₁₂	894 RCL3 895 4 896 ABS 897 L0G 899 1 809 8 1801 GSB5 1802 RTH 1803 #LBL0 184 RCL7 185 RCL6 186 RCLD 187 RCLE 188 CHS 189 CHS 189 CHS 189 CHS 189 CHS 189 CHS 189 CHS 189 CHS 189 CHS 189 CHS 189 CHS 111 RCL2 112 RCL1	Compute $\Gamma_{\rm ms}$
039 +R 048 ST06 041 R4 042 RCL7 043 X 044 LSTN 045 STN6 046 CLX 047 RCL6 048 R4 049 -	REGIS 3 s ₁₂ 4 θ ₁₂	894 RCL3 895 4BS 897 L0G 898 1 899 0 180 CSB5 182 RTN 183 #LBL0 184 RCL7 185 RCL6 186 RCLD 187 RCLE 188 CH6 189 CH6 189 CH6 111 RCL2 1112 RCL1 111 RCL2 112 RCL1 115 RCL1 115 RCL1 115 RCL2 111 RCL2 111 RCL1 115	Compute Γ_{ms}
## 839 ## 848 \$706 ## 842 \$706 ## 842 \$706 ## 844 \$707 \$700 \$700 \$700 \$700 \$700 \$700 \$7	REGIS 3 s_{12} $\frac{4}{\theta_{12}}$ S3 S4	894 RCL3 895 ABS 897 L06 898 B1 899 B1 899 B1 899 B1 899 B2 1891 GSB5 1802 RTN 1803 #LBLc 1804 RCL7 1805 RCL6 1806 RCLD 1807 RCLE 1808 CHS 1109 CSB9 1110 CHS 1111 RCL2 1112 RCL1 TEERS 5 sgn 6 Used 7 Used	Compute $\Gamma_{\rm ms}$
## 839	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	894 RCL3 895 ± 896 ABS 697 L06 898 1 899 8 180 × 181 GSB5 182 RTN 183 **LBLc 184 RCL7 185 RCLC 186 RCLD 187 RCLE 188 CH5 189 GSB9 110 CH5 111 RCL2 111 RCL2 112 RCL1 **TERS** 5 sgn 6 Used 7 Used 55 S6 S7	Compute Γ _{ms} 8 Used 9 Used S8 S9
## 839 ## 848 \$706 ## 842 \$706 ## 842 \$706 ## 844 \$707 \$700 \$700 \$700 \$700 \$700 \$700 \$7	REGIS 3 s_{12} $\frac{4}{\theta_{12}}$ S3 S4	894 RCL3 895 ABS 897 L06 898 B1 899 B1 899 B1 899 B1 899 B2 1891 GSB5 1802 RTN 1803 #LBLc 1804 RCL7 1805 RCL6 1806 RCLD 1807 RCLE 1808 CHS 1109 CSB9 1110 CHS 1111 RCL2 1112 RCL1 TEERS 5 sgn 6 Used 7 Used	Compute $\Gamma_{\rm ms}$

113 GSB8	1	169 X ≍8 ?	
114 ST00	I	170 1	
115 X≇Y		171 ABS	
116 STDA		172 LSTX	1
	ł		
117 RCLD		173 ÷	1
118 RCL1		174 ST05	
119 GSB7	1	175 RTN	
120 GTD1	1	176 #LBL8	Subroutine to add com-
		177 →R	plex numbers.
121 #LBLC	Compute Γ_{ml}		pież nambers.
122 RCL7		178 R4	
123 RCL6		179 R ↓	1
124 RCL1		180 →R	
125 RCL2		181 X2Y	1
			1
126 CHS		192 R4	
127 GSB9		183 +	1
128 CHS		184 R↓	
129 RCLE		185 +	
	1	186 Rt	1
130 RCLD	l		
131 GSB8	1	187 +P	
132 ST00	1	188 RTN	
133 X2Y	1	189 #LBL9	Subroutine to multiply
	1	190 R4	complex numbers.
134 ST0A	1		complex numbers.
135 RCL1	1	191 ×	
13€ RCLD		192 R↓	
137 GSB7	l .	193 +	
138 *LBL1	l	194 R#	
139 RCL8	l	195 RTN	
140 RCL0	1	19€ #LEL5	
141 ÷	i	197 F8?	DISPLAY ROUTINE
142 2	1	198 PRTX	IF flag 0
143 ÷	l		THEN PRINT
	l	199 F0?	
144 ENT†		200 RTH	ELSE
145 X2			DISPLAY.
145 X2		201 R/S	
145 X2 146 1		201 R/S 202 RTN	
145 X2 146 1 147 -		201 R/S	
145 X2 146 1 147 - 148 IX		201 R/S 202 RTN	
145 %2 146 1 147 - 148 JX 149 RCL5		201 R/S 202 RTN	
145 %2 146 1 147 - 148 JX 149 RCL5		201 R/S 202 RTN	
145 %2 146 1 147 - 148 JX 149 RCL5		201 R/S 202 RTN	
145 X2 146 1 147 - 148 IX 149 RCL5 150 X 151 -		201 R/S 202 RTN	
145 X2 146 1 147 - 148 IX 149 RCL5 150 X 151 X		201 R/S 202 RTN	
145 X2 146 1 147 - 148 IX 149 RCL5 150 X 151 - 152 RCLA 153 CHS		201 R/S 202 RTN	
145 X2 146 1 147 - 148 IX 149 RCL5 150 - 151 - 152 RCLA 153 CHS 154 GSB5	Display ∠ Γ	201 R/S 202 RTN	
145 X2 146 1 147 - 148 IX 149 RCL5 150 X 151 - 152 RCLA 153 CHS	Display ∠ Γ	201 R/S 202 RTN	
145 X2 146 1 147 - 148 IX 149 RCL5 150 X 151 - 152 RCLA 153 CHS 154 GSB5 155 X#Y		201 R/S 202 RTN	
145 X2 146 I 147 - 148 IX 149 RCL5 150 X 151 - 152 RCLA 153 CHS 154 GSB5 155 XZY 156 GSB5	Display \angle Γ	201 R/S 202 RTN	
145 X2 146 1 147 - 148 IX 149 RCL5 150 X 151 - 152 RCLA 153 CHS 154 GSB5 155 XEY 156 GSB5 157 RTN		201 R/S 202 RTN	
145 X2 146 I 147 - 148 IX 149 RCL5 150 X 151 - 152 RCLA 153 CHS 154 GSB5 155 X#Y 156 GSB5 157 RTM 158 #LBL7		201 R/S 202 RTN	
145 X2 146 1 147 - 148 IX 149 RCL5 150 X 151 - 152 RCLA 153 CHS 154 GSB5 155 X2Y 156 GSB5 157 RTN 158 *LBL7 159 X2		201 R/S 202 RTN	
145 X2 146 I 147 - 148 IX 149 RCL5 150 X 151 - 152 RCLA 153 CHS 154 GSB5 155 X#Y 156 GSB5 157 RTM 158 #LBL7		201 R/S 202 RTN	
145 X2 146 1 147 - 148 IX 149 RCL5 150 X 151 X 152 RCLA 153 CRLA 153 GSB5 154 X5Y 156 GSB5 157 RTN 158 #LBL7 159 X2Y 168 X2Y		201 R/S 202 RTN	
145 X2 146 1 147 - 148 IX 149 RCL5 150 X 151 - 152 RCLA 153 CHS 154 GSB5 155 X=7 156 GSB5 157 RTN 158 #LBL7 159 X2 160 X2 161 X2		201 R/S 202 RTN	
145 X2 146 1 147 - 148 IX 149 RCL5 150 X 151 RCLA 153 CHS 154 CHS 155 CHS 155 CHS 155 CHS 156 CHS 157 RTN 158 #LBL7 159 X2 160 X2 161 X2 162 -		201 R/S 202 RTN	
145 X2 146 1 147 - 148 IX 149 RCL5 150 X 151 - 152 RCLA 153 CHS 154 GSB5 155 X#Y 156 GSB5 157 RTN 158 #LBL7 159 X2 161 X2 162 - 163 1		201 R/S 202 RTN	
145	Display Γ	201 R/S 202 RTN	
145		201 R/S 202 RTN	
145	Display Γ	201 R/S 202 RTN	
145	Display Γ	201 R/S 202 RTN	
145	Display Γ	201 R/S 202 RTN	
145	Display Γ Compute sgn(B).	201 R/S 202 RTN 203 R/S	DISPLAY.
145	Display Γ Compute sgn(B).	201 R/S 202 RTN	
145	Display Γ Compute sgn(B).	201 R/S 202 RTN 203 R/S	DISPLAY.
145	Display	201 R/S 202 RTN 203 R/S	DISPLAY.
145	Display	201 R/S 202 RTN 203 R/S	DISPLAY. SET STATUS AGS TRIG DISP NO OFF
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	Compute sgn(B). LABELS nl D E ns D E	201 R/S 202 RTN 203 R/S	SET STATUS AGS TRIG DISP DISPERSION OFF DEG RI FIX
145	Display	201 R/S 202 RTN 203 R/S	SET STATUS AGS TRIG DISP NO OFF NO OFF DEG NI FIX
145	Compute sgn(B). LABELS nt D E ns d e 3 4	201 R/S 282 RTN 283 R/S	SET STATUS AGS TRIG DISP NO OFF NO OFF DEG NI FIX
145	Compute sgn(B). LABELS nt D E ns d e 3 4	201 R/S 202 RTN 203 R/S	DISPLAY.

Bilateral Design: Gain and Stability Circles, Load and Source Mapping

901	*LBLA		l		95 7	×.		
882	1		ł		85 €	1		1
863	8		l .		95 9	+		1
884	÷				960	÷		Display ρ
005	19×		l		e 61	*LBL5		DISPLAY ROUTINE
90€	RCLB				962	F0?		
807	XE		1		963	PRTX		IF flag 0
808	÷		1		864	F8?		THEN PRINT
989	STOI		Store Gp		865	RTH		ELSE
			Store Gp		966	R/S		DISPLAY.
010	RCL7		ł					DISPLAT.
011	RCL6				967	RTN		
812	RCL1				868	*LBLC		
013	CHS				869	STOI		Store pointer
014	RCL2				878	eto:		
815	CHS				871	*LBL1		Compute input stability
916	ESB9		1		872	RCLE		circles.
017	RCLE		l .		873	CHS		1
018	RCLD				874	RCLD		1
					875	RCL6		1
819	GSB8		I					1
920	STOP		I		076	RCL7		1
821	XZY		I		877	ESB9		1
822	CHS				8 78	CHS		1
823	CSB5		Display ∠r		0 79	RCL2		
824	RCLD				686	RCL1		
825	XS		i		881	ESB8		1
826	RCL6				982	XZY		1
					983	CHS		1
027	Χź		l					1
82€	-				084	ese5		Display ∠ r _{s1}
829	STOA				685	XZY		
030	RCLI		l		88€ 887	RCL1		
<i>e</i> 31	×					Xs		
832	LSTX				386	RCL€		
033	XZY				989	ΧE		1
034	1				896	-		1
035	+*				891	÷		1
83€	_							
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	÷ PCI 0							Display r _{s1}
937 970	RCLO				893	CT03		
038	RCL0 x		Diaglass		893 894	CTO3 *LBL2		Compute output stability
038 039	RCL0 × GSB5		Display r		893 894 895	CTO3 *LBL2 RCL2		
038 039 040	RCL0 X GSB5 RCLI		Display r		893 894 895 896	#LBL2 RCL2 CHS		Compute output stability
838 839 848 841	RCL0 × GSB5		Display r		893 894 895 896 897	#LBL2 RCL2 CHS RCL1		Compute output stability
838 839 848 841 842	RCL0 X GSB5 RCLI RCL3 X		Display r		893 894 895 89€ 897 898	CT03 *LBL2 RCL2 CHS RCL1 RCL6		Compute output stability
838 839 848 841 842 843	RCL0 × GSB5 RCLI RCL3		Display r		893 894 895 89€ 897 898 899	GT03 *LBL2 RCL2 CHS RCL1 RCL6 RCL7		Compute output stability
838 839 848 841 842 843 844	RCL0 X GSB5 RCL1 RCL3 X RCLB		Display r		893 894 895 89€ 897 898 899	#LBL2 RCL2 CHS RCL1 RCL6 RCL7 GSB9		Compute output stability
838 839 848 841 842 843	RCL0 X GSB5 RCL1 RCL3 X RCLB		Display r		893 894 895 896 897 898 899 188 181	#LBL2 RCL2 CHS RCL1 RCL6 RCL7 GSB9 CHS		Compute output stability
838 839 848 841 842 843 844	RCL0 X GSB5 RCL1 RCL3 X RCLB		Display r		893 894 895 89€ 897 898 899	#LBL2 RCL2 CHS RCL1 RCL6 RCL7 GSB9		Compute output stability
838 839 848 841 842 843 844 845	RCL0 X GSB5 RCL1 RCL3 X RCLB ENT† ENT†		Display r		893 894 895 896 897 898 899 188 181	#LBL2 RCL2 CHS RCL1 RCL6 RCL7 GSB9 CHS		Compute output stability
838 839 848 841 842 843 844 845	RCL0 x GSB5 RCLI RCL3 x RCLB x ENT† ENT†		Display r		893 894 895 896 897 899 180 181 182 183	#LBL2 RCL2 CHS RCL1 RCL6 RCL7 GSB9 CHS RCLE RCLD		Compute output stability
838 839 848 841 842 843 844 845	RCL0 X GSB5 RCL1 RCL3 X RCLB ENT† ENT†		Display r		893 894 895 896 897 899 180 181 182 183	#LBL2 RCL2 CHS RCL1 RCL6 RCL7 GSB9 CHS RCLE RCLD GSB8		Compute output stability
038 039 048 041 042 043 044 045 046 046 048	RCL0 X GSB5 RCLI RCL3 X RCLB ENT† ENT† RCL9 ENT†		Display r		893 894 895 896 897 698 899 180 181 182 183 184	#LBL2 #CL2 CHS RCL1 RCL6 RCL7 GSB9 CHS RCLE RCLD GSB8 X2Y		Compute output stability
838 839 848 841 842 843 844 845 846 847 848 849	RCL0 x GSB5 RCL1 RCL3 x RCLB ENT† ENT† RCL9 ENT†		Display r		893 894 895 896 897 899 180 181 182 183 184 185	CT03 *LBL2 RCL2 CHS RCL1 RCL6 RCL7 CSB9 CHS RCLE RCLD GSB8 X2Y CHS		Compute output stability circles.
938 939 941 941 942 943 944 945 946 947 949 959	RCL0 X GSB5 RCL1 RCL3 X RCLB X ENT† ENT† RCL9 ENT† + X		Display r		893 894 895 896 897 898 899 180 181 182 183 184 185 186 187	CTD3 *LBL2 RCL2 CHS RCL17 RCL6 RCL7 CSB9 CHS RCLE RCLD CSB8 X2Y CHS CSB5		Compute output stability
838 839 848 841 842 843 844 845 846 847 849 850 851	RCL0 X GSB5 RCL1 RCL3 X RCLB X ENT† ENT† ENT† + - X 1		Display r		893 894 895 896 897 898 899 180 181 182 183 184 185 186 187	CTD3 *LBL2 RCL2 CHS RCL1 RCL6 RCL7 CSB9 CHS RCLE RCLD GSB8 X2Y CHS GSB5 X2Y		Compute output stability circles.
838 839 848 841 842 843 844 845 846 847 858 859 851 851 852	RCL0 X GSB5 RCL1 RCL3 X RCLB ENT† ENT† + - X 1 +		Display r		893 894 895 896 897 898 899 188 181 182 183 185 186 187 186 187	CTD3 *LBL2 RCL2 CHS RCL1 RCL6 RCL7 CSB9 CHS RCLE RCLD CSB8 X2Y CHS CSB5 X2Y RCLD		Compute output stability circles.
838 839 848 841 842 843 844 845 846 847 849 851 852 853	RCL0 x GSB5 RCLI RCL3 x RCLB x ENT† ENT† +		Display r		893 894 895 897 898 899 180 181 182 184 185 186 187 186 187	CTD3 *LBL2 RCL2 CHS RCL1 RCL6 RCL7 CSB9 CHS RCLE RCLD GSB8 X2Y CHS GSB5 X2Y RCLD X2 RCLD		Compute output stability circles.
838 839 848 841 842 843 844 845 846 847 848 858 851 852 853 854	RCL0 x GSB5 RCLI RCL3 x RCLB x ENT† ENT† - x 1 + - X RCLI RCL9 ENT† - X RCLI RCL		Display r		893 894 895 896 897 898 899 180 183 184 185 186 187 188 189	CTD3 *LB12 RC12 RC12 RC11 RC16 RC17 CSB9 RC1E RC1D GSB8 X2Y RC16 RC16 RC16 RC16 RC17 RC10 RC16 RC10 RC16 RC10 RC16 RC10 RC16 RC10 RC16 RC10 RC16 RC10 RC16 RC16		Compute output stability circles.
838 839 848 841 842 843 844 845 846 847 849 852 851 852 853	RCL0 x GSB5 RCLI RCL3 x RCLB x ENT† ENT† +		Display r		893 894 895 896 897 899 188 181 182 183 184 187 186 187 189 118	CTD3 *LBL2 RCL2 CHS RCL1 RCL6 RCL7 CSB9 CHS RCLE RCLD GSB8 X2Y CHS GSB5 X2Y RCLD X2 RCLD		Compute output stability circles.
838 839 848 841 843 844 845 849 859 851 852 851 853 854	RCL0 x GSB5 RCLI RCL3 x RCLB x ENT† ENT† - x 1 + - X RCLI RCL9 ENT† - X RCLI RCL				893 894 895 896 897 698 899 180 181 182 183 184 185 186 187 188 189 111 111 112	CTD3 *LB12 RC12 RC12 RC11 RC16 RC17 CSB9 RC1E RC1D GSB8 X2Y RC16 RC16 RC16 RC16 RC17 RC10 RC16 RC10 RC16 RC10 RC16 RC10 RC16 RC10 RC16 RC10 RC16 RC10 RC16 RC16		Compute output stability circles.
838 839 849 841 842 843 844 845 849 851 852 852 853 855	RCL0 x SSB5 RCLI RCL3 x RCLB ENT† ENT† ENT† + - x I RCLI RCLI RCLI RCLI RCLI RCLI	2 σ ₁ ,	la la	4	893 894 895 896 897 698 899 180 181 182 183 184 185 186 187 188 189 111 111 112	CTD3 #LB1.2 RCL12 CHS RCL11 RCL6 RCL16 CHS RCLE RCLE RCLE RCLE RCLE RCLE RCLE RCLE	7 ()	Compute output stability circles. Display \angle r _{s2}
838 839 849 841 842 843 844 845 849 851 852 853 854 855	RCL0 x SSB5 RCL1 RCL3 RCLB ENT† ENT† +	θ_{11}	3 512	θ 12	893 894 895 896 897 898 899 180 181 183 184 185 196 189 118 111 111 112 STERS	RCL2 RCL1 RCL1 RCL1 RCL1 RCL1 RCL1 RCL1 RCL1	7 ΔΔ	Compute output stability circles. Display \angle r _{s2}
838 839 849 841 842 843 844 845 849 851 852 852 853 855	RCL0 x SSB5 RCLI RCL3 x RCLB ENT† ENT† ENT† + - x I RCLI RCLI RCLI RCLI RCLI RCLI	2 θ ₁₁ S ₂	la la	4	893 894 895 896 897 698 899 180 181 182 183 184 185 186 187 188 189 111 111 112	CTD3 #LB1.2 RCL12 CHS RCL11 RCL6 RCL16 CHS RCLE RCLE RCLE RCLE RCLE RCLE RCLE RCLE	7 ΔΔ S7	Compute output stability circles. Display \angle r _{s2}
838 839 849 841 842 843 844 845 846 847 852 852 853 854 855 856	RCL0 x SSB5 RCLI RCL3 x RCLB ENT† ENT† + - x L1 H RCL1 RCL1 RCL1 RCL1 RCL1 RCL1 RCL1 RCL1	θ ₁₁	3 s ₁₂ S3	θ 12	893 894 895 896 897 899 180 181 182 184 185 186 187 188 189 118 111 111 112 118 118 118 118 118 118	RCL2 RCL1 RCL1 RCL1 RCL1 RCL1 RCL1 RCL1 RCL1	S7	Compute output stability circles. Display \angle r _{s2}
838 839 849 841 842 843 844 845 849 851 852 853 854 855	RCL0 x SSB5 RCL1 RCL3 RCLB ENT† ENT† +	θ ₁₁	3 512	θ 12	893 894 895 896 897 898 899 180 181 183 184 185 196 189 118 111 111 112 STERS	RCL2 RCL1 RCL1 RCL1 RCL1 RCL1 RCL1 RCL1 RCL1		Compute output stability circles. Display \angle r _{s2}

	,					
113 -	}	169				
114 ÷		170				
115 GSB5	Display r _{s2}	173				
116 #LBL3		172	RTN			
117 LSTN		173	*LBL8			to add com-
118 1/X		17-	; →R		plex numbe	rs.
119 RCL3		173	5 R ↓			
120 ×		170	R.J			
121 RCLB		17				
122 ×		170				
123 GSB5	Display $\rho_{\rm si}$	17				
124 RTN		186				
125 *LBLB	$\Gamma_L \rightarrow \Gamma_{ms}$	18				
126 1/4	. L ·ms	18.				
127 X=Y		18			l	
128 CHS		18			1	
129 XZY					l	
		18			Subroutine	to multiply
		18			complex nu	
		18				
132 GSB7		18				
133 RCL2		18			l	
134 RCL1		19			1	
135 GSB8		19			1	
136 XZY		19				
137 CHS		19	3 R/S			
138 GSB5		ı				
139 XZY						
140 GSB5						
141 RTH						
142 #LBL&	$\Gamma_s \rightarrow \Gamma_{ml}$	- 1				- 1
143 1/X						
144 XZY						
145 CHS 146 XZY						
146 %27						
147 RCL2		1				
148 RCL1		i				
149 CSB7		- 1			l	
150 RCLE		i				
151 RCLD						
152 GSB8						
153 X#Y		- 1				
154 CHS						
155 GSB5		- 1			l	
156 X7Y		1				
157 CSB5		- 1				
158 RTH 159 #LBL7						
160 CHS	Subroutine to compute	- 1				
161 GSB8						
162 177	S ₁₂ S ₂₁					
162 1/X 163 X#Y	1					1
164 CHS	$\frac{1}{\Gamma} - s_{ii}$					1
165 XZY	1					
166 RCL3						
167 RCL4						1
168 GSB9		- 1				
100 6000	LABELS		FLAGS		SET STATUS	
AC - Varia Br. AD IC		E				
$^{A}G_{p}\rightarrow \angle r,r,\rho$ $^{B}\Gamma_{L}\rightarrow \Gamma_{ms}$ $^{C}i\rightarrow \angle r$,τ,ρ		O PRINT	FLAGS	TRIG	DISP

LABELS					FLAGS	SELSTATUS		
A G_p → Lr,r,ρ	$^{B}\Gamma_{L}\!\rightarrow\!\Gamma_{ms}$	^C i→∠r,r,ρ	D	E	0 PRINT	FLAGS	TRIG	DISP
a	${}^{b}\Gamma_{s} \rightarrow \Gamma_{ml}$	С	d	е	1	ON OFF 0 🗷 🗆	DEG 🗷	FIX 🗆
0	¹ Used	² Used	3	⁴ Used	2	1 🗆 🗵	GRAD □ RAD □	SCI □ ENG ⊠
5 DISPLAY	6	⁷ Used	8 CADD	9 CMULT	3	3 🗆 🛚		n 3

Appendix A MAGNETIC CARD SYMBOLS AND CONVENTIONS

SYMBOL OR CONVENTION	INDICATED MEANING
White mnemonic: x A	White mnemonics are associated with the user-definable key they are above when the card is inserted in the calculator's window slot. In this case the value of x could be input by keying it in and pressing \triangle .
Gold mnemonic: y x	Gold mnemonics are similar to white mnemonics except that the gold 1 key must be pressed before the user-definable key. In this case y could be input by pressing 1 E .
x ∳ y ∆	♦ is the symbol for ENTER. In this case ENTER. is used to separate the input variables x and y. To input both x and y you would key in x, press ENTER., key in y and press A.
X A	The box around the variable x indicates input by pressing (x)
(x) A	Parentheses indicate an option. In this case, x is not a required input but could be input in special cases.
→x A	→ is the symbol for calculate. This indicates that you may calculate x by pressing key A.
→x, y, z	This indicates that x , y , and z are calculated by pressing \triangle once. The values would be printed in x , y , z order.
→x; y; z	The semi-colons indicate that after x has been calculated using \mathbf{A} , y and z may be calculated by pressing $\mathbf{R/S}$.
→ ''x '', y A	The quote marks indicate that the x value will be "paused" or held in the display for one second. The pause will be followed by the display of y.
◆ x A	The two-way arrow \Leftrightarrow indicates that x may be either output or input when the associated user-definable key is pressed. If numeric keys have been pressed between user-definable keys, x is stored. If numeric keys have not been pressed, the program will calculate x.

SYMBOLS AND CONVENTIONS (Continued)

SYMBOL OR CONVENTION	INDICATED MEANING
P?	The question mark indicates that this is a mode setting, while the mnemonic indicates the type of mode being set. In this case a print mode is controlled. Mode settings typically have a 1.00 or 0.00 indicator displayed after they are executed. If 1.00 is displayed, the mode is on. If 0.00 is displayed, it is off.
START	The word START is an example of a command. The start function should be performed to begin or start a program. It is included when initialization is necessary.
DEL A	This special command indicates that the last value or set of values input may be deleted by pressing A.
→x; A	Three dots () indicate that additional output follows. See User Instructions for complete description of variables output.

Notes



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