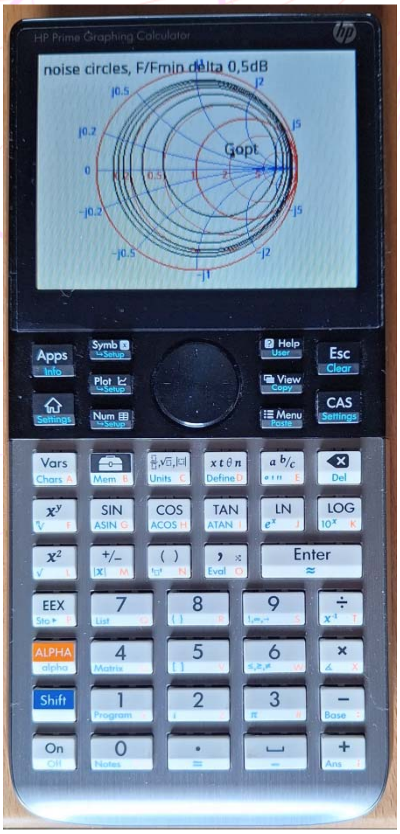
Scattering matrix S-parameters computation for simple RF-circuits with HP Prime® (RPN - modus)



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This program collection is for computations of scattering matrix ***S***-parameters for simple RF-cicuits with the HP calculator Prime [1], [2], [3].

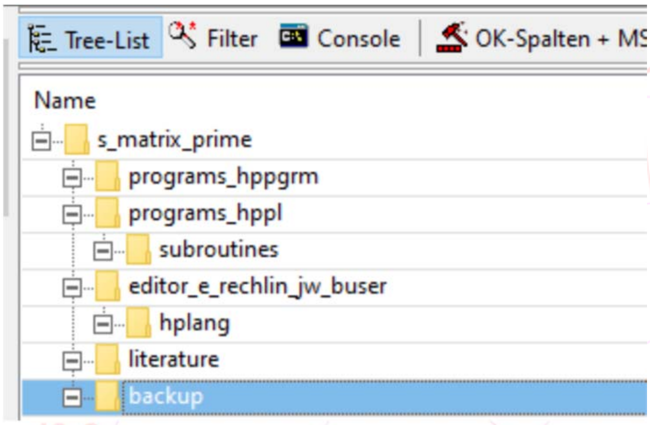
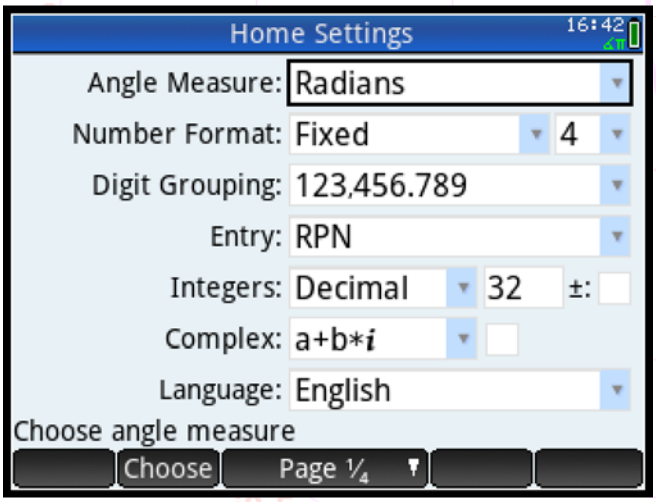
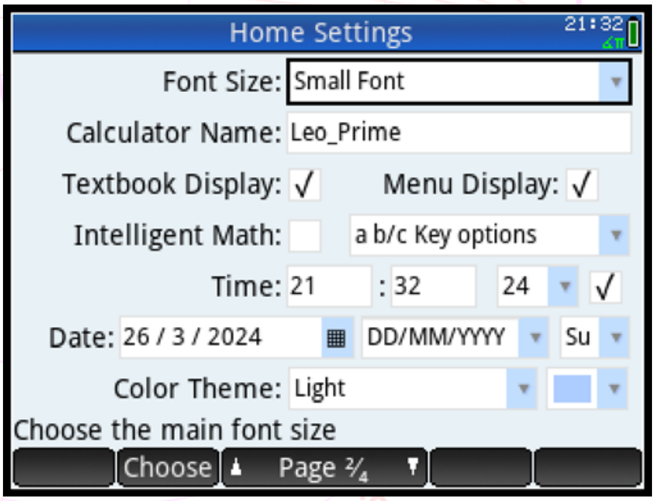


Fig. 01

After unzipping *s_matrix_prime.zip* you should get the the directory structure shown in Fig. 01.
In the directory *_hppl you find all programs in the editible *.hppl format. For this application you should use E. Rechlin‘s and J.W. Buser‘s modification of the notepad++ editor, see directory editor_e_rechlin_jw_buser or in hpcalc.org too. Subroutines in *.hppl format are placed in the subdirectory subroutines. All compiled programs with their subroutines are placed in the directory *_hppgrm. Mentioned literature and a backup with all programs and variables are in directories with the same name.





Here are the home settings. Important are Radians and RPN.

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	variable	content
1	CTB	$\boldsymbol{C}^T$-matrix base/gate
2	CTO	$\boldsymbol{C}^T$-matrix $\begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}$
3	CTE	$\boldsymbol{C}^T$-matrix emitter/source
4	HV	help variable content by you
5	JWC	value from program JOMEGALC for C
6	JWL	value from program JOMEGALC for L
7	NPB	noise parameter base/gate
9	NPE	noise parameter emitter/source
10	NPI	noise parameter your input

	variable	content
11	CTI	result matrix $NNCT(NPI) \to CTI$
11	RCT	result matrix $\boldsymbol{C}^T$
12	RSP	result matrix $\boldsymbol{S}$
13	SPB	$\boldsymbol{S}$-matrix base/gate
14	SPE	$\boldsymbol{S}$-matrix emitter/source
15	SPO	$\boldsymbol{S}$-matrix $\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$
16	SPI	$\boldsymbol{S}$-matrix your input
17	TPB	$\boldsymbol{T}$-matrix base/gate
18	TPE	$\boldsymbol{T}$-matrix emitter/source

Before using the program you must define your own user variables with
ALPHA ALPHA name Enter .
and use the variables names in the table above please for first using program collection,

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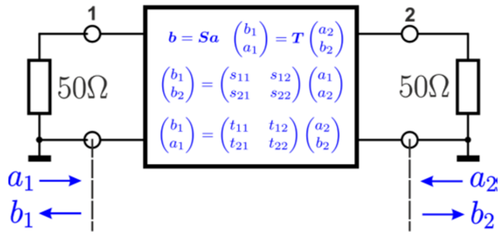
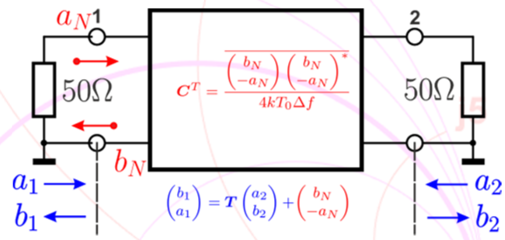


The variables *SP** (* ÷ *E,B,C,S,G,D,I*) contain the ***S***-parameters, *TP** (* ÷ *E,B,C,S,G,D,I*) are the ***T***-paramters and with the programs *STOT* or *TTOS* you can compute into each other. The transistor is an example for any other two port of your choice.

$$SP* = \begin{pmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{pmatrix}$$

$$TP* = \begin{pmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{pmatrix}$$



The two port noise properties are described with noise waves in form of the transfer noise wave matrix ***C**^{T}* [3]. All relations between ***C**^{T}* and the noise parameters are given in the appendix [3].

$$CT* = \begin{pmatrix} ct_{11} & ct_{12} \\ ct_{21} & ct_{22} \end{pmatrix}$$

$$F = F_{min} + \frac{4R_n}{50\Omega|1+\Gamma_{opt}|^2} \frac{|\Gamma - \Gamma_{opt}|^2}{1 - |\Gamma|^2} = F_{min} + C_N \frac{|\Gamma - \Gamma_{opt}|^2}{1 - |\Gamma|^2}$$

F_{min}, R_n , Γ_{opt} are the noise parameters. They are typically for each two port. We can merge R_n and Γ_{opt} to C_N for a better interpretation of the noise figure *F*. For an amplifier F_{min} and C_N should be small.The noise paramters are in *NP** (* ÷ *E,B,C,S,G,D,I*). With the programs *NNCT* and *NCNP* we can convert into one another.

$$NP* = \begin{pmatrix} F_{min} \\ Rn \\ C_N \\ \Gamma_{opt} \end{pmatrix}$$

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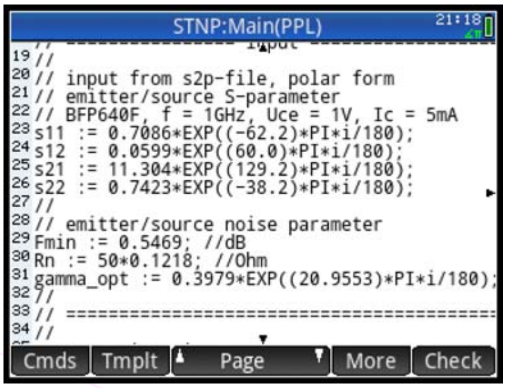
Tab. 02

	program	input	output
1	$NCNP$	$\boldsymbol{C}^T$	$\begin{pmatrix} F_{min}/\mathrm{dB} \\ R_n/\Omega \\ C_N \\ \Gamma_{opt} \end{pmatrix}$
2	$NNCT$	$\begin{pmatrix} F_{min}/\mathrm{dB} \\ R_n/\Omega \\ C_N \\ \Gamma_{opt} \end{pmatrix}$	$\boldsymbol{C}^T$
3	$NNPI$	edit program input noise paramters from datasheet	noise parameters for computing $\rightarrow NPI$
4	$NCIR$	noise parameters	noise circles
5	$ATAN2$	y, x	$-\pi \leq \varphi \leq +\pi$
6	$SMITH$		Smith-chart z-version
7	TCM	$\begin{pmatrix} a & b \\ c & d \end{pmatrix}$	$\begin{pmatrix} a^* & c^* \\ b^* & d^* \end{pmatrix}$
8	$STNP$	edit program input $\boldsymbol{S}$ paramters from datasheet	$\boldsymbol{S}$, noise parameters for computing $\rightarrow$ SPE, SPB, TPE, TPB CTE, CTB, NPE, NPB
9	$SSPI$	edit program input $\boldsymbol{S}$ paramters from datasheet	$\boldsymbol{S}$ parameters for computing $\rightarrow SPI$
10	$SSKS$	$\boldsymbol{S}$	stability circle in Smith-chart source region
11	$SSKL$	$\boldsymbol{S}$	stability circle in Smith-chart load region
12	$STOT$	$\boldsymbol{S}$	$\boldsymbol{T}$
13	$STOY$	$\boldsymbol{S}$	$\boldsymbol{Y}$
14	$TTOS$	$\boldsymbol{T}$	$\boldsymbol{S}$




```
// ================ input ==============================
//
// input from s2p-file, polar form
// emitter/source S-parameter
// BFP640F, f = 1GHz, Uce = 1V, Ic = 5mA
s11  := 0.7086*EXP((-62.2)*PI*i/180);
s12  := 0.0599*EXP((60.0)*PI*i/180);
s21  := 11.304*EXP((129.2)*PI*i/180);
s22  := 0.7423*EXP((-38.2)*PI*i/180);
//
// emitter/source noise parameter
Fmin := 0.5469; //dB
Rn := 50*0.1218; //Ohm
gamma_opt := 0.3979*EXP((20.9553)*PI*i/180);
//
// =====================================================
```

We start mit the program *STNP*. This program contains as an example the ***S***- and noise parameters of a transistor from an *.s2p file for the frequency *freq* = 1GHz. All following computations will be made at this frequency. If you want to change the frequency then you must change the data here. The program *STNP* puts the data in the variables and converts them from emitter to base circuit too, custom ending **E* or **B*, see table please. Ist equi-valent for using source and gate circuits E->S, B->G.

For using inductors and capacitors we must compute at the frequency 1GHz their nomalized impedances and admittances. At first we use the Programm *JOMEGALC* with the input „1E9 [Enter] [ALPHA] [ALPHA] *JOMEGALC* [Enter]"

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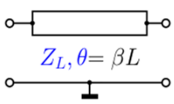
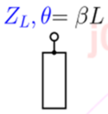
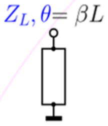
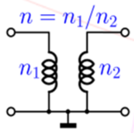
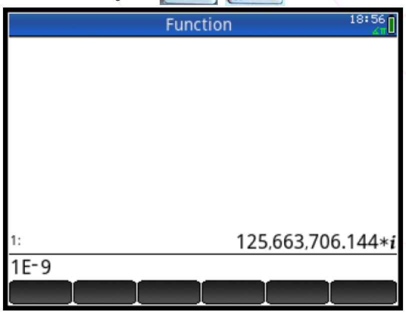
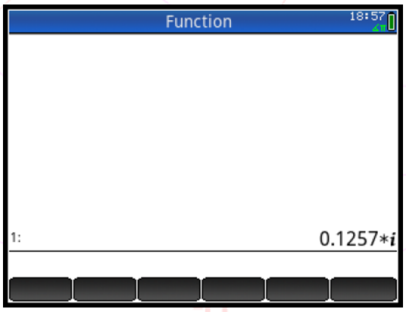
Tab. 03

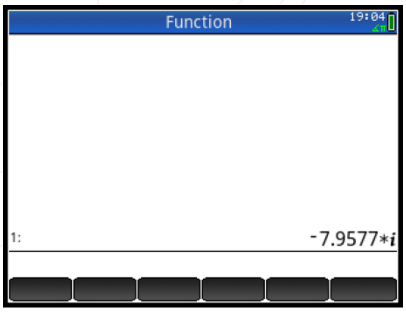
	circuit	equations	program	input	output
1		$\Gamma = \frac{Z_L/50\Omega - 1}{Z_L/50\Omega + 1}$ $s_{11} = s_{22} = \frac{\Gamma(1 - e^{-j2\theta})}{1 - \Gamma^2 e^{-j2\theta}}$ $s_{12} = s_{21} = \frac{e^{-j\theta}(1 - \Gamma^2)}{1 - \Gamma^2 e^{-j2\theta}}$	LSL	$Z_L/\Omega, \theta/°$	
2		$y = j(50\Omega/Z_L)\tan(\theta)$	LPO	$Z_L/\Omega, \theta/°$	
3		$y = (50\Omega/Z_L)/(j\tan(\theta))$	LPS	$Z_L/\Omega, \theta/°$	
4		$s_{11} = -s_{22} = \frac{n^2 - 1}{n^2 + 1}$ $s_{12} = s_{21} = \frac{2n}{n^2 + 1}$	TRA	n	
5		$z' = (j2\pi freq)/50\Omega$ $y' = (j2\pi freq) \cdot 50\Omega$	$JOMEGALC$	$freq$/Hz	variable JWL JWC

If we have an inductor with 1e-9 H then by tipping
„ ALPHA alpha ALPHA alpha *JWL* Enter ≈ 1E9 +/– × “ we get the normalized impedance 0.127*i.

With keys Shift ÷ results the normalized admittance -7.9577*i.







For a capacitor with the variable *JWC* at first you get the normalized admittance and then the impedance.

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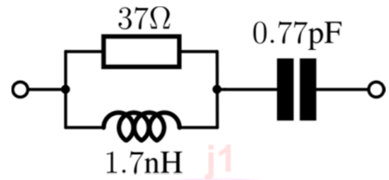
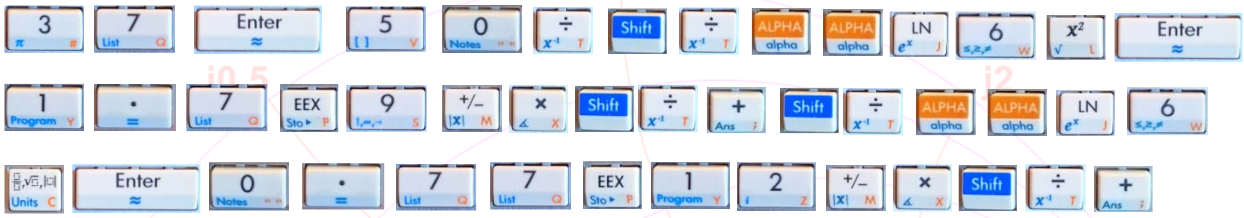
Here is a little combination from R, L and C. Resitors must be normalized with 50Ω.

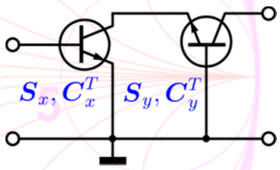


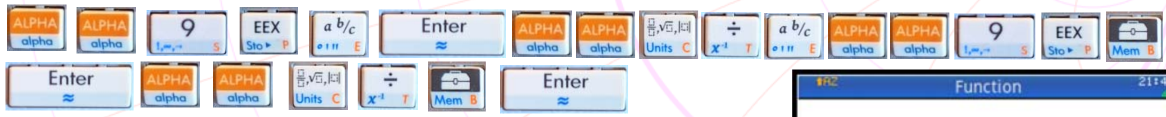


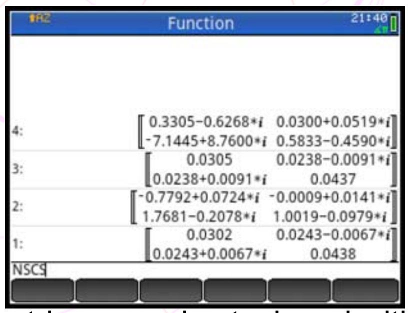
z = 0.0569-3.9357*i

At parallel circuits you can add admittances only as well as at series circuits impedances!

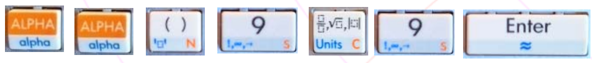
The inputs for models of ideal transmission lines are Z_L/Ω and angle/°. In Tab. 04 there are two sorts of programs, one mit first letter *N* or *S. N….* computes signal and noise *S….* signal only. We use the cascode circuit as an example. By using the program *STNP* in the variables are *SPE*, *SPB* and *CTE*, *CTB* the ***S***- and noise wave matrices from the emitter and base circuit of the transistor respectively. In the cascode circuit the emitter circuit is the first, so we make the input





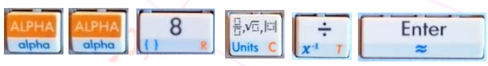


In stack are 1-4 *CTB*, *SPB*, *CTE*, *SPE*. Now we tipp

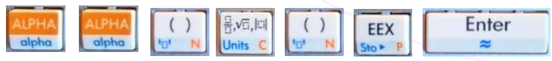


(*NSCS*)

and the Prime calculate the cascode. On the screen we see the cascode *S*-matrix. This ***S***-matrix and the ***C***^{T}-matrix are saved in the variables *RSP*, *RCT* too. With

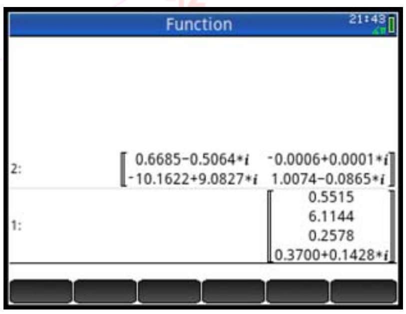


(*RCT*) the ***C***^{T}-matrix comes in stack and with



(*NCNP*)

we see the cascode noise parameters



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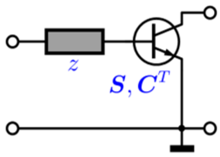
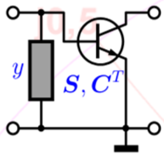
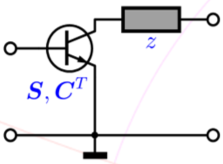
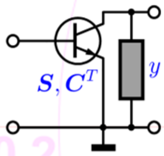
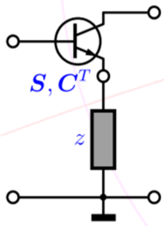
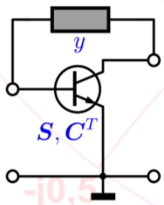
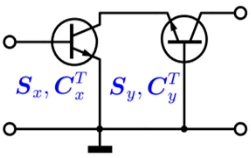
Tab. 04

	circuit	program	results in variables
1		$NSIZ(\boldsymbol{S}, \boldsymbol{C}^T, z)$ $SSIZ(\boldsymbol{S}, z)$	RSP, RCT RSP
2		$NSIY(\boldsymbol{S}, \boldsymbol{C}^T, y)$ $SSIY(\boldsymbol{S}, y)$	RSP, RCT RSP
3		$NSOZ(\boldsymbol{S}, \boldsymbol{C}^T, z)$ $SSOZ(\boldsymbol{S}, z)$	RSP, RCT RSP
4		$NSOY(\boldsymbol{S}, \boldsymbol{C}^T, y)$ $SSOY(\boldsymbol{S}, y)$	RSP, RCT RSP
5		$NSSZ(\boldsymbol{S}, \boldsymbol{C}^T, z)$ $SSSZ(\boldsymbol{S}, z)$	RSP, RCT RSP
6		$NSPY(\boldsymbol{S}, \boldsymbol{C}^T, y)$ $SSPY(\boldsymbol{S}, y)$	RSP, RCT RSP
7		$NSCS(\boldsymbol{S}_x, \boldsymbol{C}_x^T, \boldsymbol{S}_y, \boldsymbol{C}_y^T)$ $SSCS(\boldsymbol{S}_x, \boldsymbol{S}_y)$	RSP, RCT RSP

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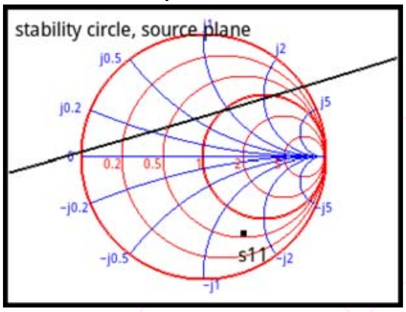
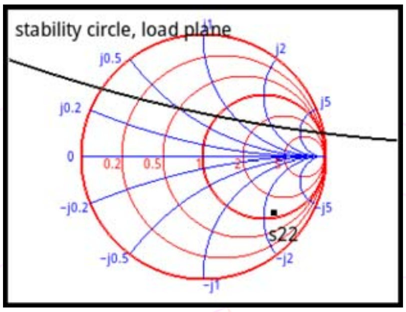
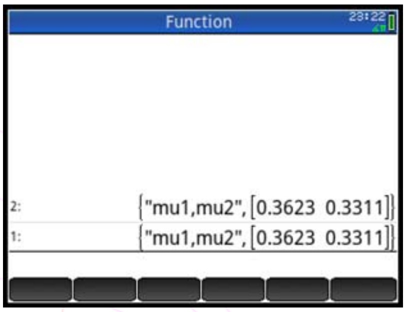
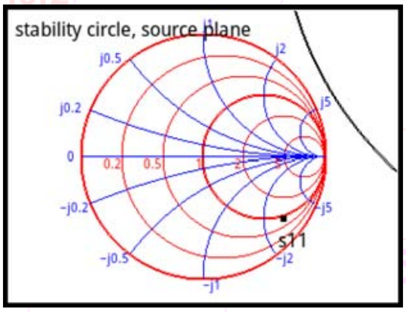
Now we will investigate the stability. For this we start with the emitter circuit, we bring with *SPE* | *ENTER* |the ***S***-parameter in the stack and choose at first the program *SSKS* | *ENTER* | . We see the stability circle in the source plane. After press *ESC* the stability parameter µ1, µ2 will be shown [3]. Similary we get with the program *SSKL* the stability in the load plane.

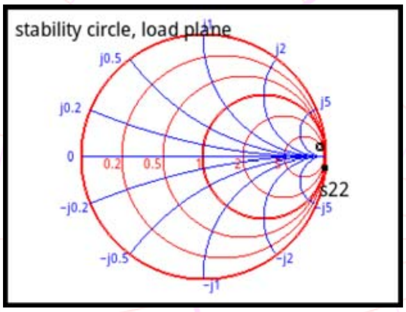


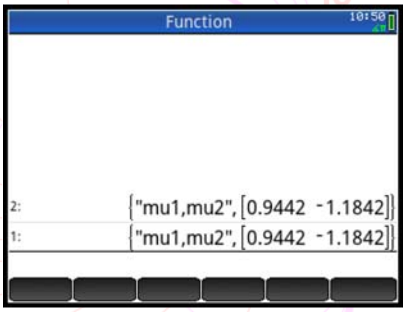




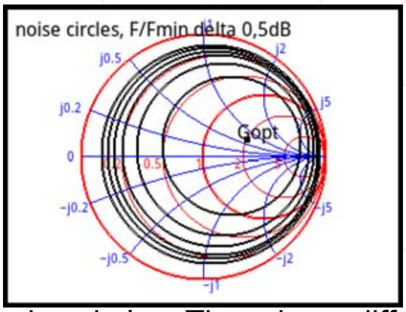
The stability circles cut the Smith chart. Because $|s_{11}|$ <1 and $|s_{22}|$<1 the center of Smith chart is in the stable sector. As comparison we make the same procedure with the ***S***-paramters of cascode circuit are as result in variable *RSP*.

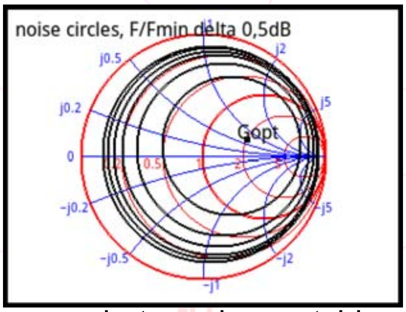


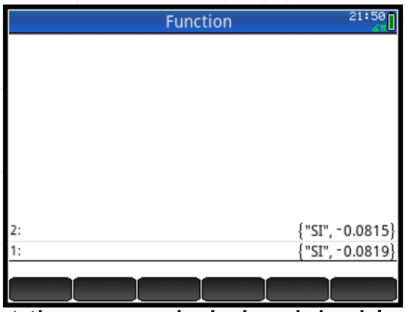




Now $|s_{11}|$ <1, so the center in the load plane is stable. The stability circle is very small In the closeness of open point. $|s_{22}|$>1, we see no stability circle in the source plane. This circle is outside of the unit circle and the whole Smith chart for passive parts is not stable. With *NPE* | *ENTER* | *NCIR* | *ENTER* for emitter and *RCT* | *ENTER* | *NCNP* | *ENTER* | *NCIR* | *ENTER* | similar for cascode results the program *NCIR* shows the







noise circles. There is no difference, but a noise matching at the cascode is inadvisable, because$|s_{22}|$>1. After *ESC* you see on screen „*SI*". The noise parameters must satisfy the Schwarz inequality SI < 0 [3].

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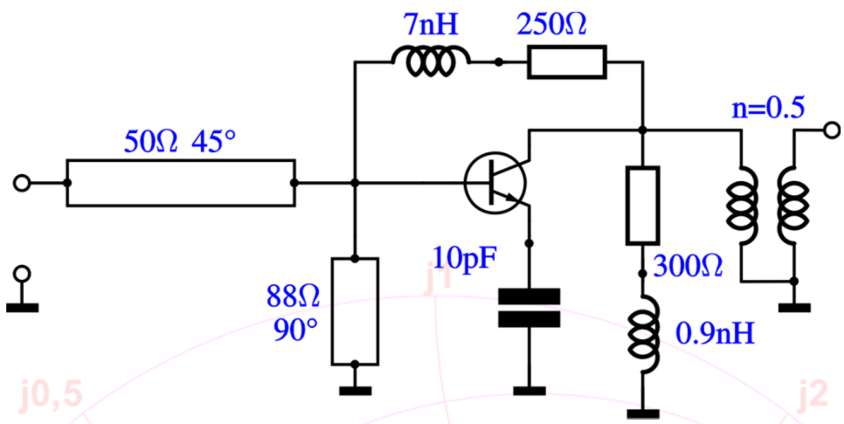
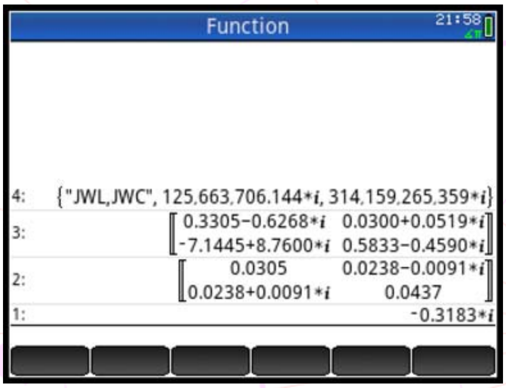
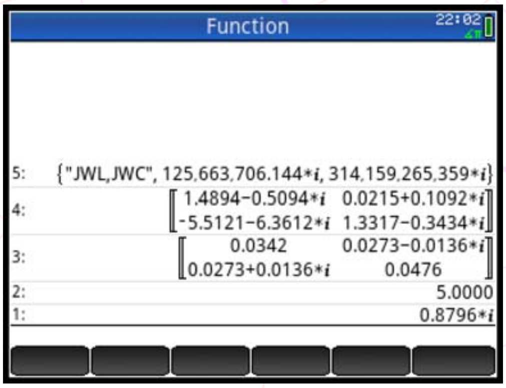


The amplifier above should be an example for using the other programs. For safety we start with | 1E9 | *ENTER* | *JOMEGALC* | *ENTER* | *SPE* | *ENTER* | *CTE* | Enter | *JWC* | | 10E-12 | *x* | *x*$^{-1}$ |



| *NSSZ* | *ENTER* | *RCT* | *ENTER* | 250 | *ENTER* | 50 |  | *JWL* | *ENTER* | 7E-9 | x |



| + | x^{-1} | *NSPY* | *ENTER* | *RCT*| *ENTER* |

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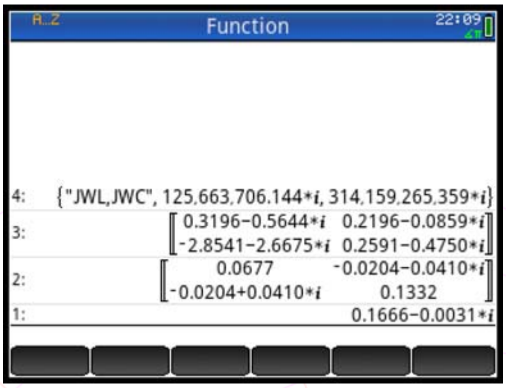
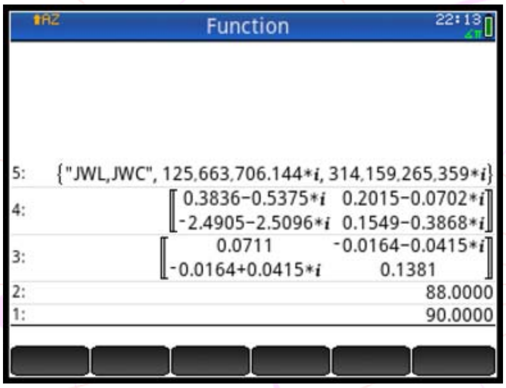
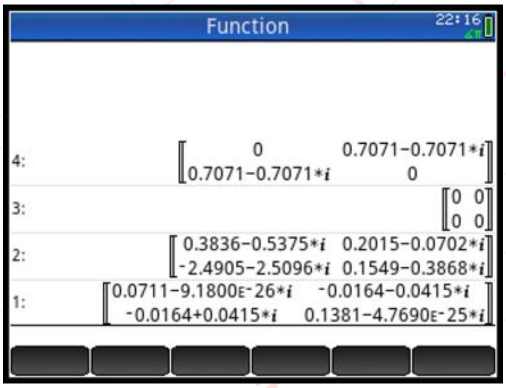
| 300 | *ENTER* | 50 | | *JWL* | *ENTER* | .9E-9 | x | + | x^{-1} |



| *NSOY* | *ENTER* | *RCT* | *ENTER* | 88 | *ENTER* | 90 | *ENTER* |



| *LPS* | *ENTER* | *NSIY* | *ENTER* | | 50 | *ENTER* | 45 | *ENTER* | *LSL* | *ENTER* |
| *CTO* | *ENTER* | *RSP* | *ENTER* | *RCT* | *ENTER* |



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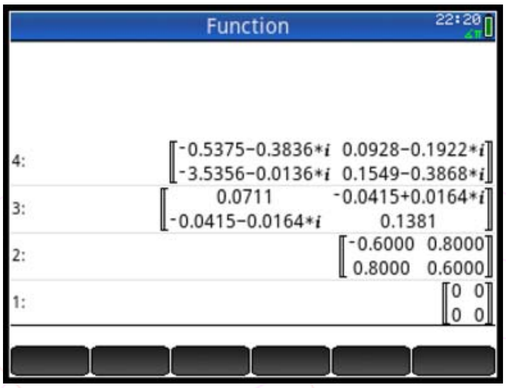
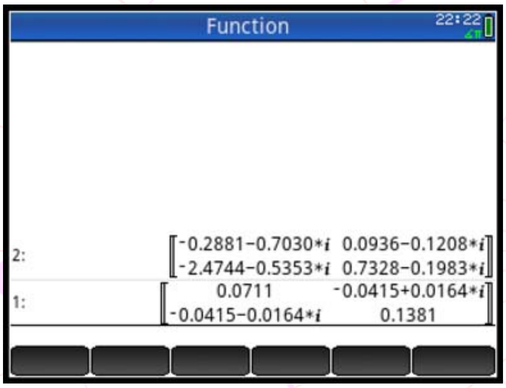
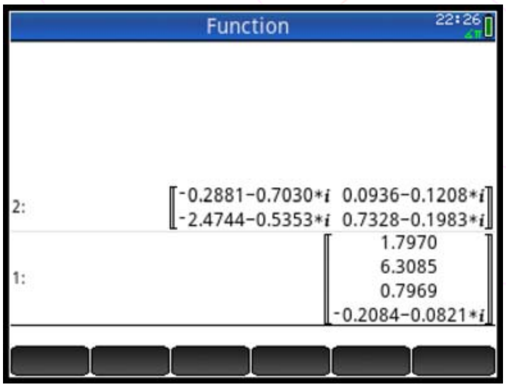
| *NSCS* | *ENTER* | *RCT* | *ENTER* | 0.5 | *ENTER* | *TRA* | *ENTER* | *CTO* | *ENTER* |

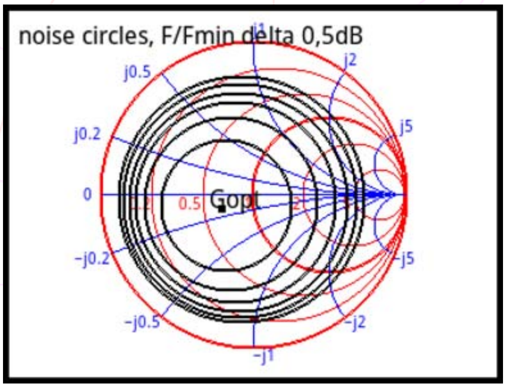


| *NSCS* | *ENTER* | *RCT* | *ENTER* |



Now we see in stack 2 the ***S***- and stack 1 the ***C***^{T}- matrix of the whole amplifier. With | *NCNP* | *ENTER* | we get the noise parameters and pressing | *NCIR* | *ENTER* | the noise circles with *SI* = -0.2444.





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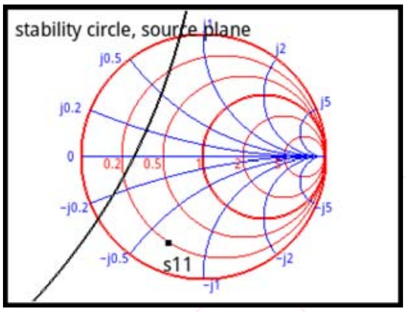
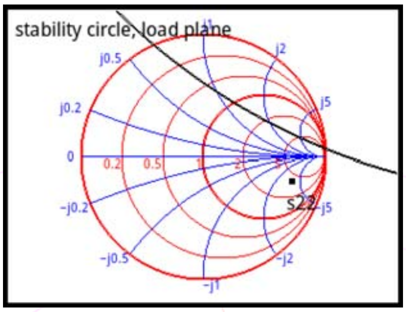
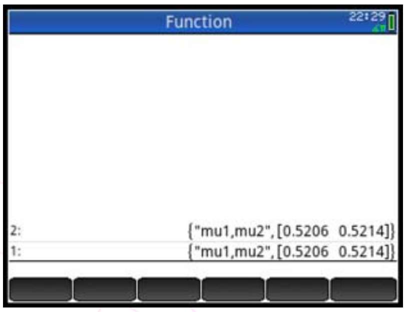
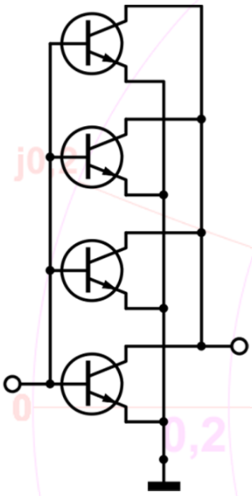
To show the stability circles we delete the screen, pressing
| *RSP* | *ENTER* | *SSKS* | *ENTER* | for the source plan and then
| *RSP* | *ENTER* | *SSKL* | *ENTER* | for the load plane

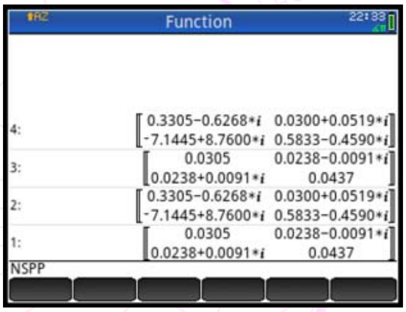


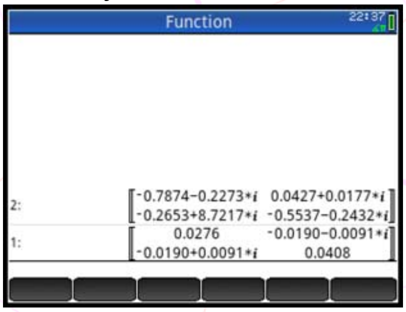


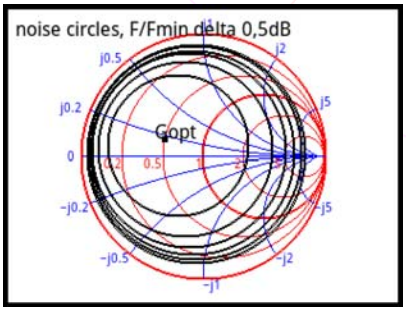


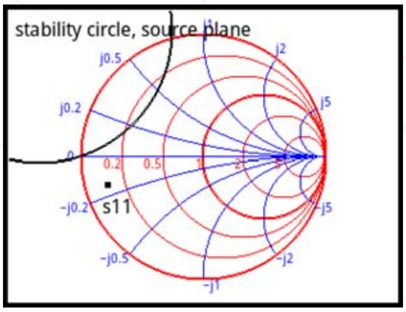


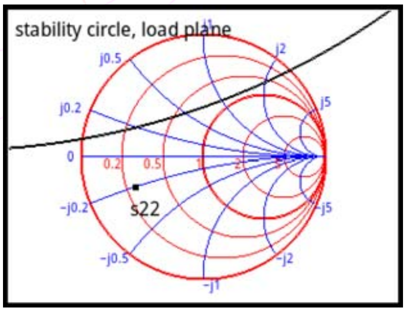
On the left side is a circuit with four transistors in parallel connection. This circuit can be compute by pressing keys in the following order | *SPE* | *ENTER* | *CTE* | *ENTER* | *SPE* | *ENTER* | *CTE* | *ENTER* | | *NSPP* | *ENTER* |. Now we have two transitors parallel. Then | *RCT* | *ENTER* | *SPE* | *ENTER* | | *CTE* | *ENTER* | *NSPP* | *Enter* | for three transistors and once more | *RCT* | *ENTER* | *SPE* | *ENTER* | | *CTE* | *ENTER* | *NSPP* | *Enter* | for four transistors. With |*RCT*| *ENTER* | *NCNP* | |*Enter*| *TRN* | *ENTER* | the noise parameter in transpose form will be shown, Here are the noise and stability circles.











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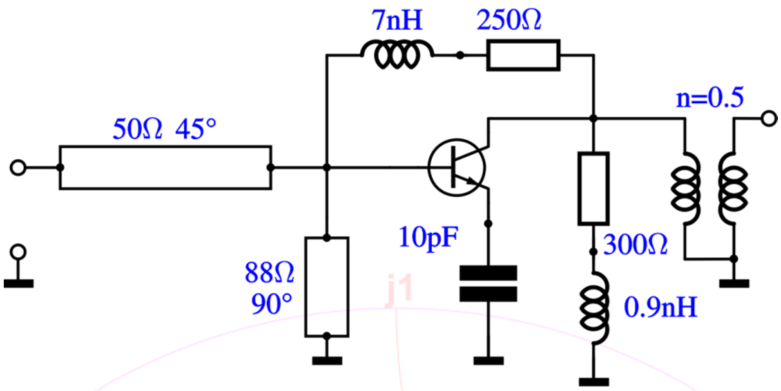


If noise is not a point of interest, we use all programs with *S*.. as first letter. For the amplifier we has the following order of pressing keys

| 1e9 | *ENTER* | *JOMEGALC* | *ENTER* | *SPE* | *ENTER* | *JWC* | *ENTER* | 10E-12 | x |

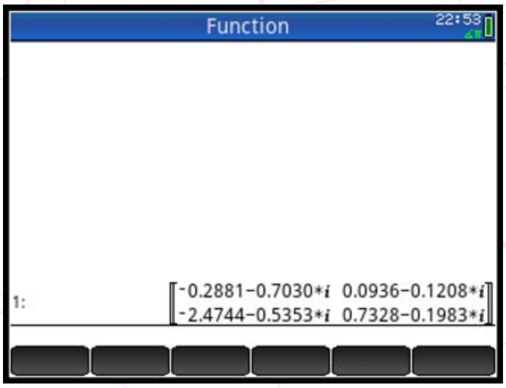
| x^{-1} | *SSSZ* | *ENTER* | 250 | *ENTER* | 50 |  | *JWL* | *ENTER* | 7E-9 | x | + | x^{-1} | *SSPY* |

| *ENTER* | 300 | |*ENTER* | 50 |  | *JWL* | *ENTER* | .9E-9 | x | + | x^{-1} | *SSOY* | *ENTER* |

| 0.5 | *ENTER* | *TRA* | *ENTER* | *SSCS* | *ENTER* | 88 | *ENTER* | 90 | *ENTER* | *LPS* |

| *ENTER* | *SSIY* | *ENTER* |  | 50 | *ENTER* | 45 | *ENTER* | *LSL* | *ENTER* | *RSP* |

| *ENTER* | *SSCS* | *ENTER* |



You can see, it is very simple, thanks RPN. Also, at series connection you must add impedances and at parallel one admittances. For separate input of S- or noise parameters you can use *SSPI* or *NNPI*.

I hope, this program collection will help you. For me it was a great pleasure using and programming the Prime calculator. At my study for sixty years I use sliding rule and table books. So times have changed.

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have fun Siegfried Martius

March 2024

	subroutine	input	output
1	$atan2(y,x)$	y,x	φ/radian
2	$nnct(np)$	noise parameter np	$\boldsymbol{C}^T$
3	$scs(sx,sy)$	$\boldsymbol{S}_x, \boldsymbol{S}_y$	$\boldsymbol{S}_{x,y}$
4	$smith()$		Smith-chart
5	$stot(s)$	$\boldsymbol{S}$	$\boldsymbol{T}$
6	$tcm(m)$	$\boldsymbol{M}$	$\boldsymbol{M}^*$
7	$xp(x)$	x	pixel xpp
8	$yp(y)$	y	pixel ypp

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References:

[1] Martius, Siegfried: *Die Streumatrix des gegengekoppelten Transistors und ihre Anwendung bei der rechnergestützten Schaltungsanalyse/-synthese im Mikrowellenbereich*
Nachrichtentechnik, Elektronik, Berlin, 36 (1986) 7, 260 - 264

[2] Martius, Siegfried: *Rauschkennwerte und Streumatrix des gegengekoppelten Transistors und ihre Anwendung bei der rechnergestützen Schaltungsanalyse /-synthese im Mikrowellenbereich*
Nachrichtentechnik, Elektronik, Berlin, 36 (1987) 9, 329 – 333

[3] Martius, Siegfried: *Wellenbeschreibung elektrischer Netzwerke mit der Streu-matrix*
Wiesbaden: Springer Fachmedien, 1st ed. 2023
https://doi.org/10.1007/978-3-658-38875-1

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