Qucs

A Tutorial

BJT Modeling and Verification

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warning

This chapter will describe an RF design issue using QUCS. The author assume that the basic manipulation of qucs is known. You will find herein mainly a MacOsX description that is close to a linux or unices architecture.

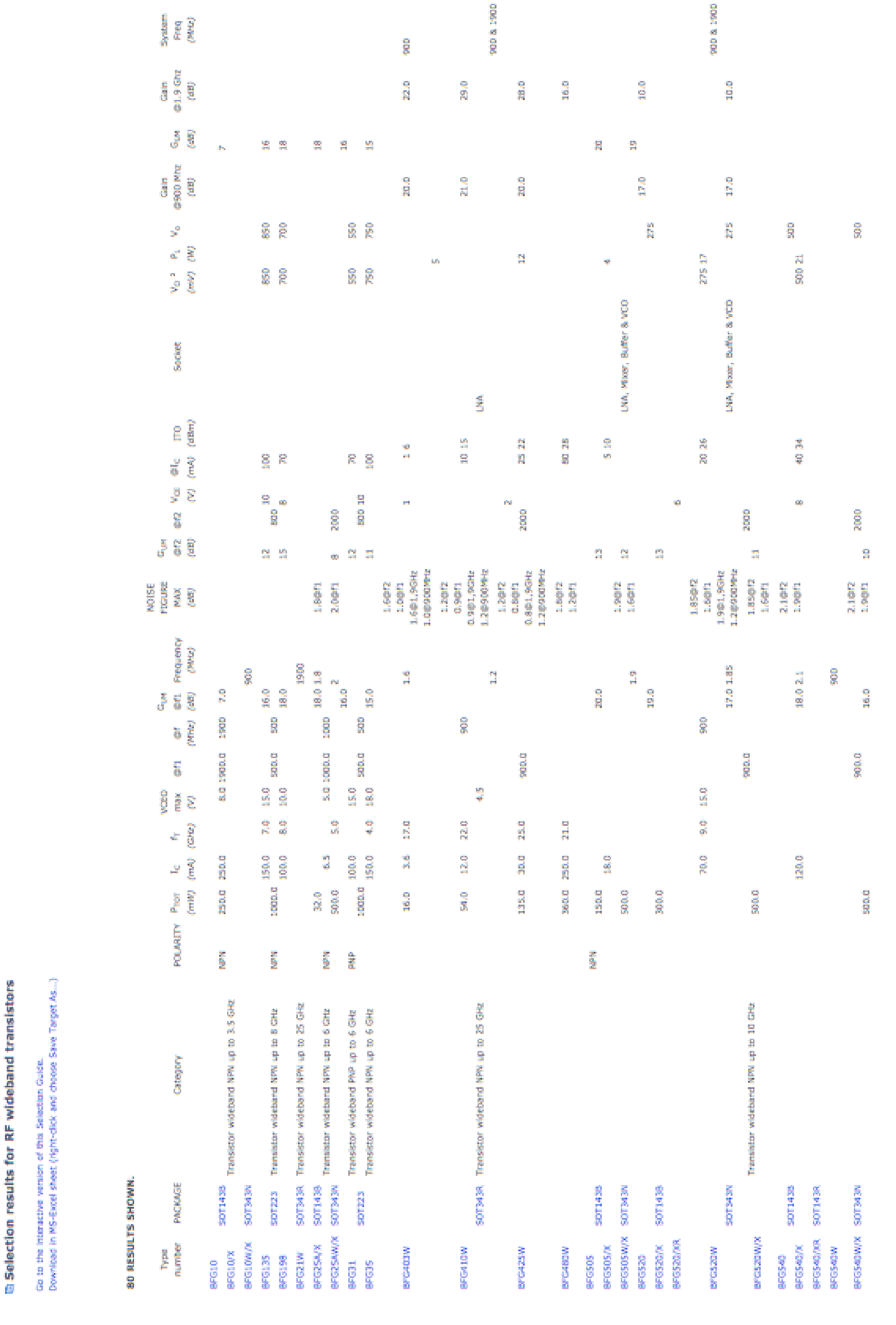
choice of transistor

The choice has been made to choose among the Philips RF wideband transistor library. These components are easy to find, with resonnable prices.
This list could be found at `http://www.semiconductors.philips.com/`.
A resume of these transistors can be found in the figure 1
I will not discuss herein, the reason [1] why of the final choice, but the $BFG425w$ is the candidate. It offers high gain, with low figure noise (if LNA consideration) high transistion frequency (25 GHz), its emitter is thermal lead, low feedback capacitance. This device could be used in RF front end, analog or digital cellular, radar detectors, pagers, SATV, oscillators. It is in a SOT343R package suitable for small integration.
The maximum acheivable gain is 20 dB with 25 mA, $V_{ce} = 2$ V at 2 GHz and $25°C$. The third order intercept point in these conditions is typically $22dBm$.
These parameter should be compatible with our need. Here are the spice parameter of the device.

```
.SUBCKT BFG425W 1 2 3
L1   2 5 1.1E-09
L2   1 4 1.1E-09
L3   3 6 0.25E-09
Ccb  4 5 2.0E-15
Cbe  5 6 80.0E-15
Cce  4 6 80.0E-15
Cbpb 5 7 1.45E-13
Cbpc 4 8 1.45E-13
Rsb1 6 7 25
Rsb2 6 8 19
Q1 4 5 6 6 NPN

.MODEL NPN NPN
+ IS = 4.717E-17  + BF = 145    + NF = 0.9934
```

[1] regarding current, F_t , V_{ce} , power dissipation, etc ...



Selection results for RF wideband transistors

Go to the interactive version of this Selection Guide.
Download in MS-Excel sheet (right-click and choose Save Target As...)

80 RESULTS SHOWN.

Type number	PACKAGE	Category	POLARITY	P_{TOT} (mW)	I_C (mA)	f_T (GHz)	VCEO max (V)	@f1	@f (MHz)	G_{UM} @f1 (dB)	Frequency (MHz)	NOISE FIGURE MAX (dB)	G_{UM} @f2 (dB)	@f2	V_{CE} (V)	@I_C (mA)	ITO (dBm)	Socket	V_O ² (mV)	P_L (W)	V_o	Gain @900 Mhz (dB)	G_{UM} (dB)	Gain @1.9 Ghz (dB)	System Freq (MHz)
BFG10																									
	SOT143B		NPN	250.0	250.0		8.0	1900.0	1900	7.0													7		
BFG10/X		Transistor wideband NPN up to 3.5 GHz																							
BFG10W/X	SOT343N										900														
BFG135					150.0	7.0	15.0			16.0			12		10	100			850		850		16		
	SOT223	Transistor wideband NPN up to 8 GHz	NPN	1000.0				500.0	500					800											
BFG198					100.0	8.0	10.0			18.0			15		8	70			700		700		18		
BFG21W	SOT343R	Transistor wideband NPN up to 25 GHz									1900														
BFG25A/X	SOT143B			32.0						18.0	1.8	1.8@f1											18		
		Transistor wideband NPN up to 6 GHz	NPN		6.5		5.0	1000.0	1000																
BFG25AW/X	SOT343N			500.0		5.0					2	2.0@f1	8	2000											
										16.0													16		
BFG31		Transistor wideband PNP up to 6 GHz	PNP		100.0		15.0						12			70			550		550				
	SOT223			1000.0				500.0	500					800	10										
BFG35		Transistor wideband NPN up to 6 GHz			150.0	4.0	18.0			15.0			11			100			750		750		15		
BFG403W				16.0	3.6	17.0					1.6	1.6@f2 1.0@f1 1.6@1,9GHz 1.0@900MHz			1	1	6					20.0		22.0	900
																				5					
BFG410W				54.0	12.0	22.0			900			1.2@f2 0.9@f1 0.9@1,9GHz 1.2@900MHz				10	15					21.0		29.0	
	SOT343R	Transistor wideband NPN up to 25 GHz					4.5											LNA							
											1.2														900 & 1900
															2										
BFG425W				135.0	30.0	25.0		900.0				1.2@f2 0.8@f1 0.8@1,9GHz 1.2@900MHz		2000		25	22			12		20.0		28.0	
BFG480W				360.0	250.0	21.0						1.8@f2 1.2@f1				80	28							16.0	
BFG505			NPN																						
	SOT143B			150.0						20.0			13										20		
BFG505/X					18.0											5	10			4					
BFG505W/X	SOT343N			500.0								1.9@f2 1.6@f1	12					LNA, Mixer, Buffer & VCO							
											1.9												19		
BFG520																					275	17.0		10.0	
										19.0															
BFG520/X	SOT143B			300.0									13												
BFG520/XR															6										
					70.0	9.0	15.0		900			1.85@f2 1.6@f1 1.9@1,9GHz 1.2@900MHz				20	26		275	17					
BFG520W																									900 & 1900
	SOT343N									17.0	1.85							LNA, Mixer, Buffer & VCO			275	17.0		10.0	
		Transistor wideband NPN up to 10 GHz						900.0						2000											
BFG520W/X				500.0								1.85@f2 1.6@f1	11												
BFG540																									
	SOT143B																				500				
BFG540/X					120.0					18.0	2.1	2.1@f2 1.9@f1			8	40	34		500	21					
BFG540/XR	SOT143R																								
BFG540W											900														
BFG540W/X	SOT343N							900.0				2.1@f2 1.9@f1		2000							500				
				500.0						16.0			10												

Figure 1: transistor table from philips semiconductor

```
+ VAF = 31.12  + IKF = 0.304 + ISE = 3.002E-13
+ NE = 3  + BR = 11.37  + NR = 0.985
+ VAR = 1.874  + IKR = 0.121  + ISC = 4.848E-16
+ NC = 1.546  + RB = 14.41 + IRB = 0
+ RBM = 6.175  + RE = 0.1779  + RC = 1.780
+ CJE = 3.109E-13  + VJE = 0.9  + MJE = 0.3456
+ CJC = 1.377E-13 + VJC = 0.5569 + MJC = 0.2079
+ CJS = 6.675E-13 + VJS = 0.4183 + MJS = 0.2391
+ XCJC = 0.5  + TR = 0.0  + TF = 4.122E-12
+ XTF = 68.2  + VTF = 2.004  + ITF = 1.525
+ PTF = 0  + FC = 0.5501  + EG = 1.11
+ XTI = 3  + XTB = 1.5
.ENDS
```

Since the model used in SPICE and in QUCS rely on a gummel-poon modelisation, and since the level of modelisation is the same, some quite direct conversion could be used to create the library for QUCS.
To use directly this file, you will need to store the file in an other directory from the project one (a small bug taken into account). Then it should work but some there are still some issues on the parameters itselves, This is the reason why we will proceed in an other way.
The data sheet could be found on the philips web site.

Philips Semiconductors — Product specification

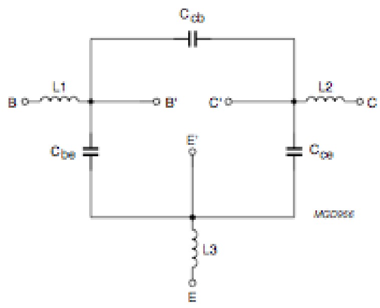
NPN 25 GHz wideband transistor — BFG425W

SPICE parameters for the BFG425W die

SEQUENCE No.	PARAMETER	VALUE	UNIT
1	IS	47.17	aA
2	BF	145.0	–
3	NF	0.993	–
4	VAF	31.12	V
5	IKF	304.0	mA
6	ISE	300.2	fA
7	NE	3.000	–
8	BR	11.37	–
9	NR	0.985	–
10	VAR	1.874	V
11	IKR	0.121	A
12	ISC	484.8	aA
13	NC	1.546	–
14	RB	14.41	Ω
15	IRB	0.000	A
16	RBM	6.175	Ω
17	RE	177.9	mΩ
18	RC	1.780	Ω
19 (1)	XTB	1.500	–
20 (1)	EG	1.110	eV
21 (1)	XTI	3.000	–
22	CJE	310.9	fF
23	VJE	900.0	mV
24	MJE	0.346	–
25	TF	4.122	ps
26	XTF	68.20	–
27	VTF	2.004	V
28	ITF	1.525	A
29	PTF	0.000	deg
30	CJC	137.7	fF
31	VJC	556.9	mV
32	MJC	0.207	–
33	XCJC	0.500	–
34 (1)	TR	0.000	ns
35 (1)	CJS	667.5	fF
36 (1)	VJS	418.3	mV
37 (1)	MJS	0.239	–
38	FC	0.550	–
39 (2)(3)	C_{bp}	145	fF
40 (2)	R_{sb1}	25	Ω
41 (3)	R_{sb2}	19	Ω

Notes

1. These parameters have not been extracted, the default values are shown.
2. Bonding pad capacity C_{bp} in series with substrate resistance R_{sb1} between B′ and E′.
3. Bonding pad capacity C_{bp} in series with substrate resistance R_{sb2} between C′ and E′.



$QL_B = 50$; $QL_E = 50$; $QL_{B,E}(f) = QL_{B,E}\sqrt{(f/f_c)}$
f_c = scaling frequency = 1 GHz.

Fig.14 Package equivalent circuit SOT343R2.

List of components (see Fig.14)

DESIGNATION	VALUE	UNIT
C_{be}	80	fF
C_{cb}	2	fF
C_{ce}	80	fF
L1	1.1	nH
L2	1.1	nH
L3 (note 1)	0.25	nH

Note

1. External emitter inductance to be added separately due to the influence of the printed-circuit board.

1998 Mar 11 — 9

Figure 2: spice parameter extract from philips data sheet

library creation

Remember that when creating a device, it is almost always mandatory to read of have a look at on how the model is done is the technical documentation. It is very to understand the limitation, and how we can correct some data if needed. The mian pity is that a lot of commercial software are quite obscure on the real model they use and their limitation ; QUCS is quite exceptionnal on this point this the complete modeling is explain theoretically in a special technical paper.

In order to conduct these test, we need to create a model of our component. To perform this you should create the file that contain all the libraries, this file is stored under

`/usr/local/share/qucs/library/philips_RF_widebande_npn.lib`

You can edit this file with `vi`. You need to add the following line :

```
<Qucs Library 0.0.7 "philips RF wideBand">

<Component BFG425W>
  <Description>
    RF wideband NPN 25GHz
    2V, 25mA, 20dB , 2000MHz
    Manufacturer: Philips Inc.
    NPN complement: BFG425W
    --------------------------
    based on spice parameter from philips
    --------------------------
    sept 2005  thierry
  </Description>
  <Model>
<_BJT T_BFG425W_ 1 480 280 8 -26 0 0 "npn" 1 "47.17e-10"
1 "1" 1 "1" 1 "0.304" 1 "0.121" 1 "31.12" 1 "1.874" 0
"300.2e-15" 1 "3" 1 "484.8e-10" 1 "1.546" 1 "145" 1 "11.37"
1 "6.175" 1 "0" 1 "1.78" 1 "0177.9e-3" 1 "014.41" 1 "310.9e-15"
1 "0.900" 1 "0.346" 1 "137.7e-15" 1 "0.5569" 1 "0.207" 1 "0.500"
1 "667.5e-15" 1 "0.4183" 1 "0.239" 1 "0.550" 1 "4.122e-12" 1
"68.2" 1 "2.004" 1 "1.525" 1 "0.0" 1 "26.85" 1 "0.0" 0 "1.0" 0
"1.0" 0 "0.0" 0 "1.0" 0 "1.0" 0 "0.0" 0>
  </Model>
</Component>
```

You can replace the 1 by 0, this will remove the visible checkbox, the fact to place a 1 first enable the user to change and or view the parameters that are being used. A trick to provide all the required syntax is to fill a NPN into the schematics, perform a copy on the device, you should then have the model in the clipboard, just paste into to file and add the description and the markup language boundaries. The syntaxe is explained in the help at the topic *description of the qucs file formats*. Then the device is visible in the `Component Library Tool` as mentionned in figure 3.

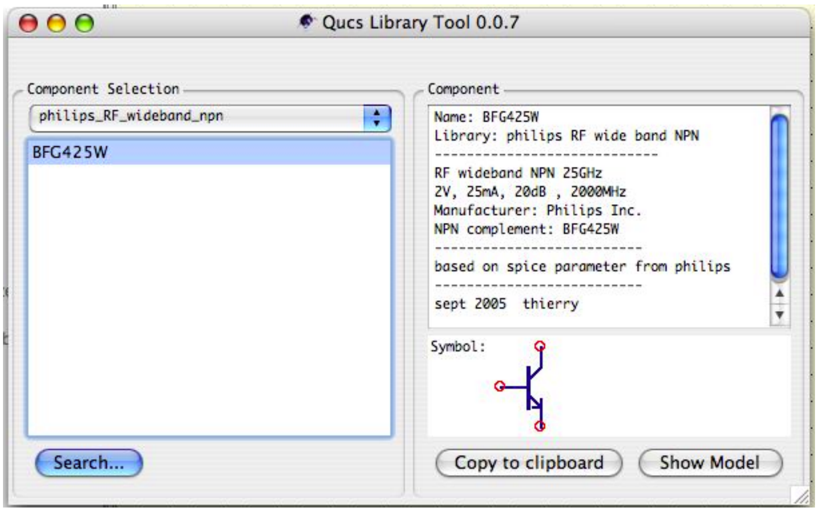


Figure 3: QUCS Component Library showing the new component

By doing this you haved the possibility to reuse the device as much as you want, and you can debug devices in a more easy way.
Warning : in this section we have only describe the die of the device, for the parasitic from the package, we will be obliged to describe this circuit, but later on.

device library verification

The first step, before using the device in a application, is to verify the model you use. Especially since this model has been created by the user. In order to proceed, you need to rely on exact data : that is to say the official datasheet.
it this step, you will need to create a project especially for the device verification. It is good to keep a trace of the device verification, since you could have different use of this device, so it is good to be able to redo some simulation around the model itself.
The created project should look that the figure 4.

```
project name :  model_verif_bfg425w
project location : $HOME/.qucs/
```

For the validation we will need to use a specific bias of the device : I_c should be $25mA$, therefore I_b should be $300\mu A$

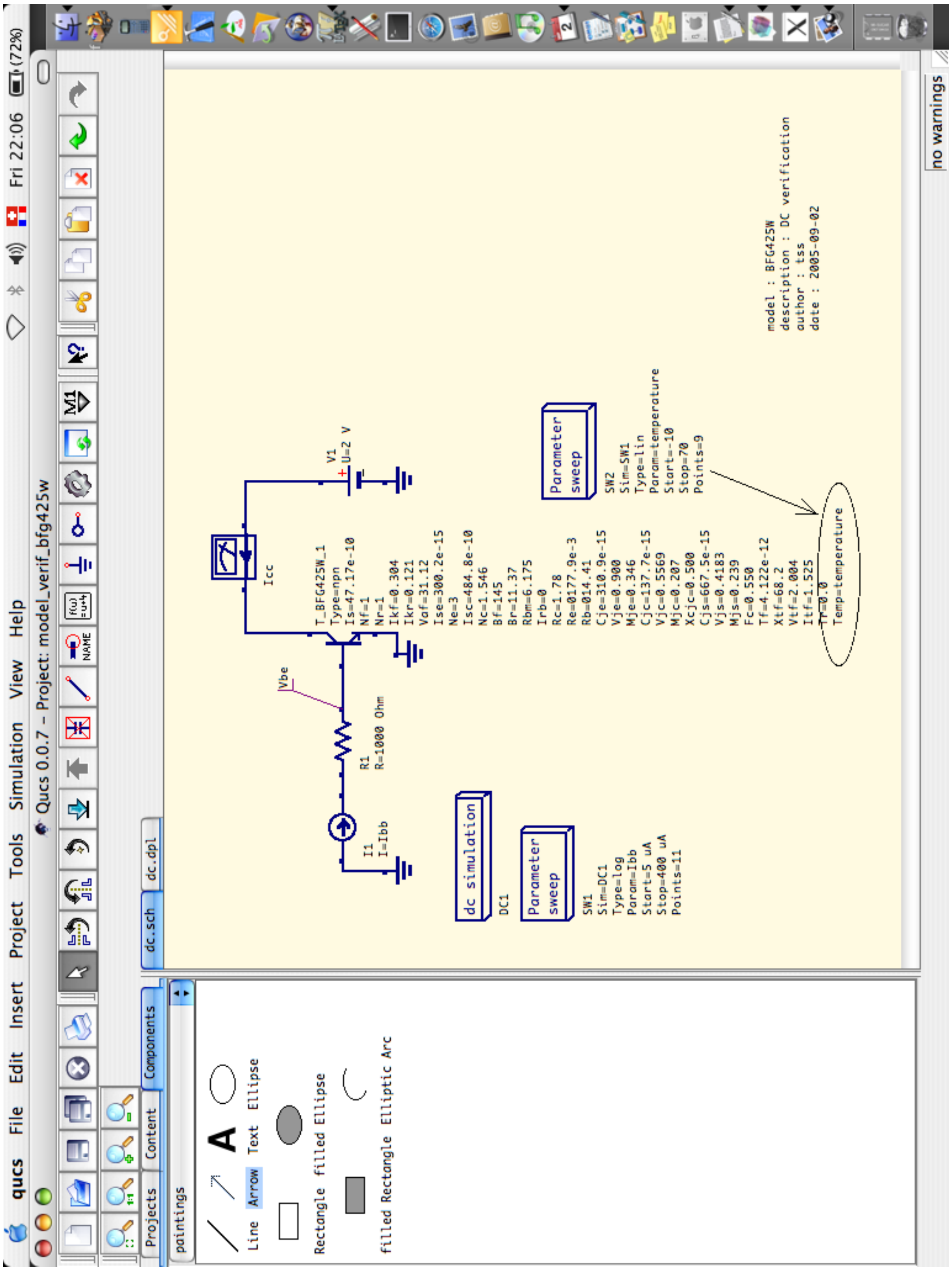


Figure 4: QUCS project for model verification

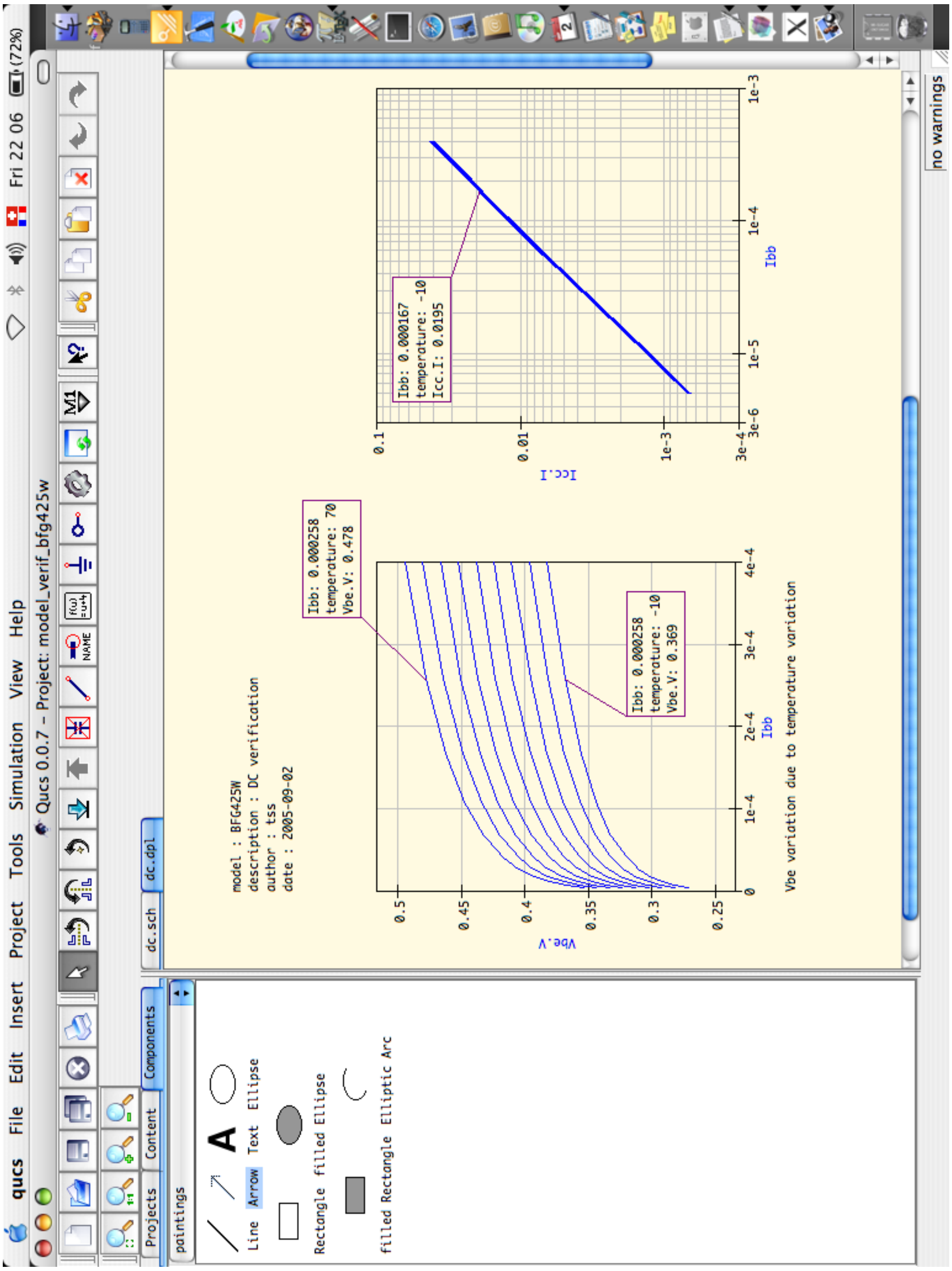
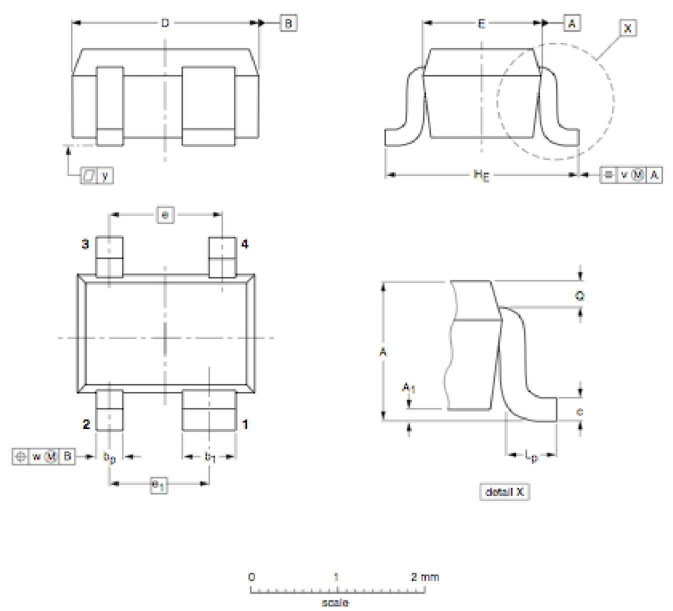


Figure 5: DC validation and temperature

parasitic description of the package

In order to simulate properly the device, you need to used the correct package, that is to say the $SOT343R$ in our case, as mentionned on the philips web site (see fig. 6).
Eventhough the device has two emitter, the model used has only one emitter. The parasitic of this model are shoyn in the spice netlist described in the choice of the transistor and reproduced in a schematic (see fig. 8). These parameter are always critical to extract, either you have the knowledge to do it or then you should rely on the piece of information given by the device manucfacturer. It is also very difficult to figure out what have to be changed in such description of the device. Some fitting have been performed using 3D electromagnetic software in the time domain based on MOM methods to verify these parameters.
Philips fifth generation double poly silicon wideband technology uses a steep emitter doped profile resulting in transition frequencies over 20 GHz, and with poly base contacts a low base resistance is obtained. Via the buried layer, the collector contact is brought out at the top of the die. The substrate is connected directly to the emitter package lead, resulting in improved thermal performance (see fig 7).
From this schematics you can edit the symbol that could be used in the next simulation file. To proceed type $F3$ or edit circuit symbol from the file menu. Simply drw a npn transistor and come back to the schematic by re-pressing $F3$.

Plastic surface mounted package; reverse pinning; 4 leads **SOT343R**



DIMENSIONS (mm are the original dimensions)

UNIT	A	A_1 max	b_p	b_1	c	D	E	e	e_1	H_E	L_p	Q	v	w	y
mm	1.1 0.8	0.1	0.4 0.3	0.7 0.5	0.25 0.10	2.2 1.8	1.35 1.15	1.3	1.15	2.2 2.0	0.45 0.15	0.23 0.13	0.2	0.2	0.1

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	EIAJ			
SOT343R						97-05-21

Figure 6: $SOT343R$ package description

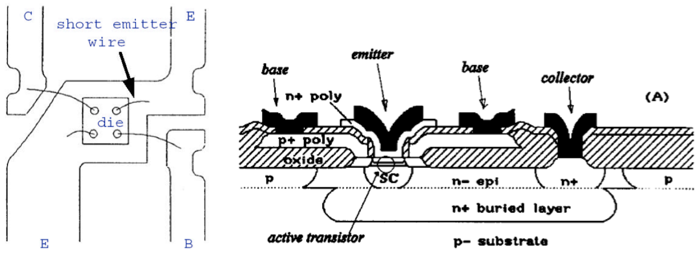


Figure 7: die connection if the fifth generation transistor from philips

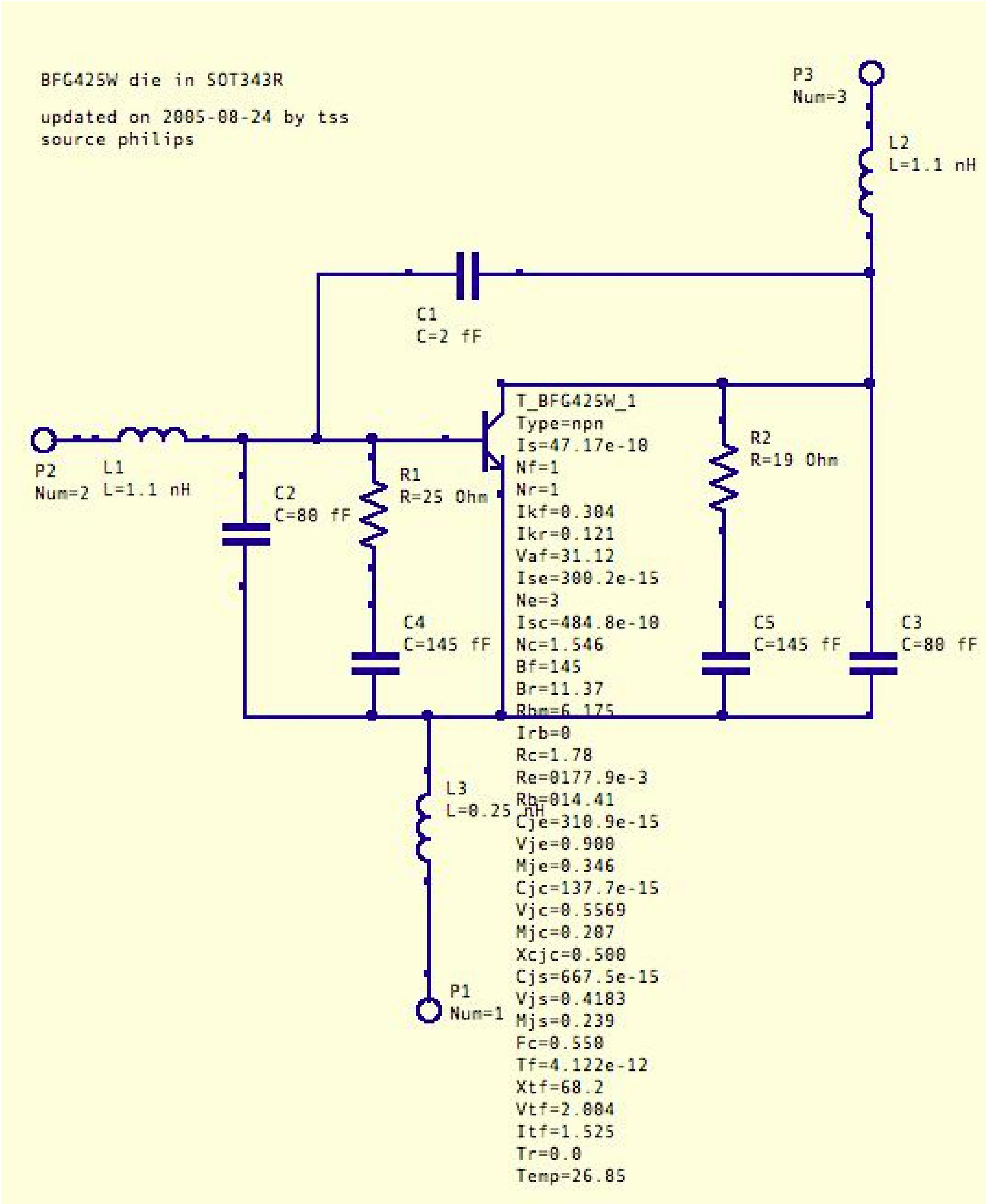


Figure 8: $bfg425W$ in $sot343R$ package description

small signal S parameter verification

In this section we will need to redraw a new schematics using the model we have created, plus some extra components to place the measurements ports [2].
You should have a schematics like the one mentionned in fig9.

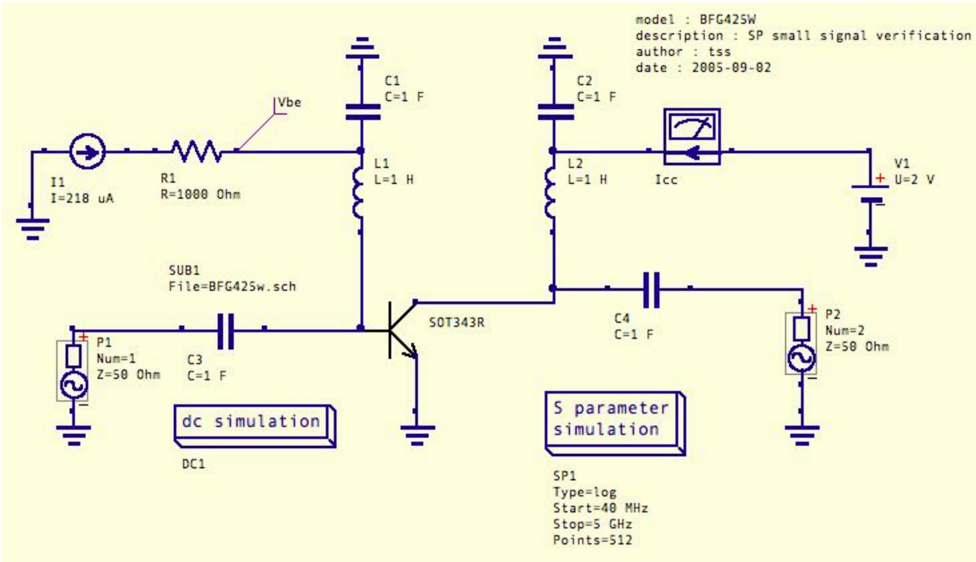


Figure 9: schematics used for S parameters simulation

The components used to verify the model could be strange (inductor of $1H$ and capacitor of $1F$) It is normal since we need to have a very wide band response on the circuit, and since we want to caracterize only the active device, and compare with the datasheet. An other way is to use DC bloc or DC feed or bias Tee to provide the power supply to the component. This is the right way to do it.
you should then create a display to visualize the S parameters : generally s_{11} and s_{22} are in the smith and s_{12} and s_{21} are in polar
We have now to compare these results with the measured parameters from philips :

```
! Filename: 225bfg425.001
! BFG425W Field C1
! V1=8.667E-001V,V2=2.000E+000V, I1=3.585E-004A, I2=2.496E-002A
!                 S11               S21               S12               S22
!Freq(GHz)  Mag      Ang      Mag      Ang      Mag      Ang      Mag      Ang
```

[2]We will another method when we will use the device in a real project

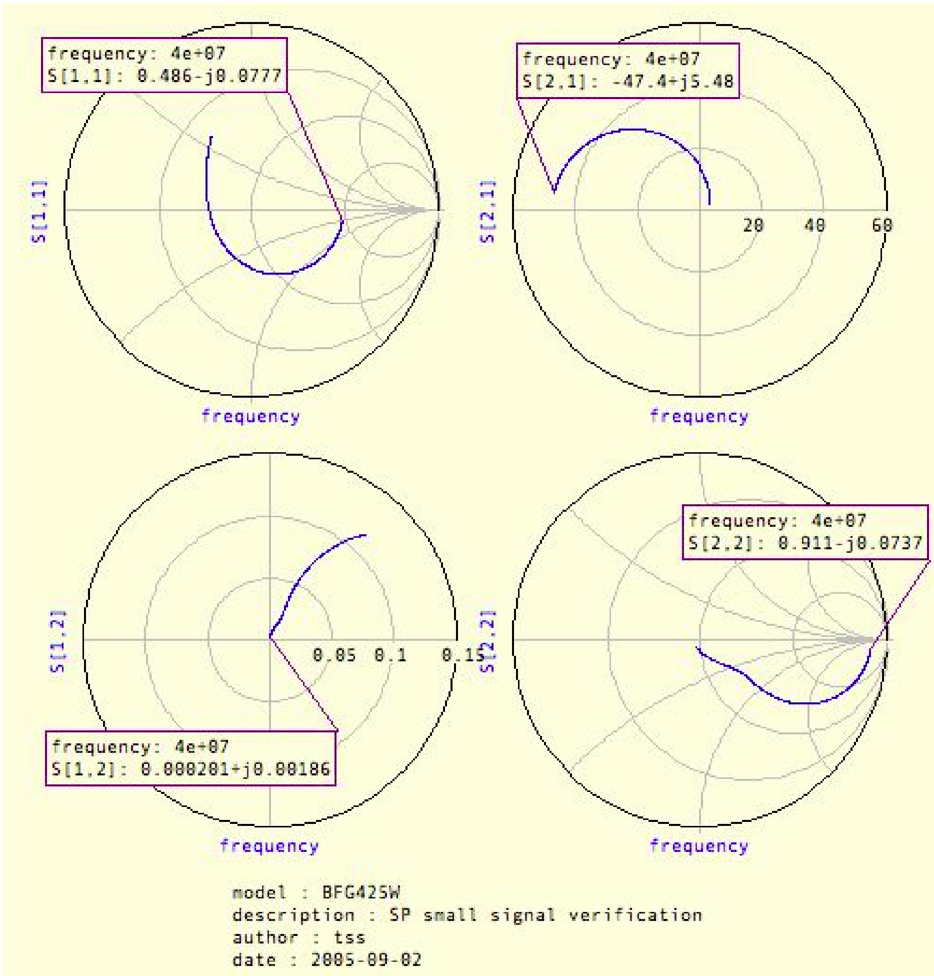


Figure 10: S parameters simulation for model verification

```
# GHz   S   MA   R 50
   0.040    0.325  -8.696   38.472 173.381    0.002  71.865    0.923  -
3.072
   0.100    0.331 -23.004   37.457 164.549    0.005  83.280    0.915  -
9.551
   0.200    0.315 -44.455   34.771 150.487    0.008  75.947    0.863 -
18.965
   0.300    0.296 -63.008   31.364 138.811    0.012  71.608    0.794 -
26.449
   0.400    0.278 -79.654   27.951 128.829    0.015  68.186    0.725 -
32.076
   0.500    0.265 -94.339   24.856 120.248    0.017  65.974    0.664 -
36.332
   0.600    0.254 -106.508   22.159 113.362    0.020  64.514    0.613 -
39.533
   0.700    0.246 -116.820   19.885 107.530    0.022  63.362    0.569 -
42.071
   0.800    0.240 -126.472   17.964 102.255    0.024  62.701    0.533 -
44.121
   0.900    0.235 -134.500   16.345  97.645    0.027  61.910    0.504 -
45.968
   1.000    0.232 -141.743   14.958  93.487    0.029  61.280    0.479 -
47.614
   1.100    0.230 -148.265   13.770  89.661    0.031  60.570    0.457 -
49.172
   1.200    0.230 -154.216   12.748  86.091    0.033  59.878    0.438 -
50.696
   1.300    0.230 -159.761   11.850  82.773    0.036  59.238    0.421 -
52.103
   1.400    0.231 -164.776   11.070  79.671    0.038  58.509    0.406 -
53.483
   1.500    0.233 -169.782   10.383  76.687    0.040  57.719    0.392 -
54.842
   1.600    0.234 -174.382    9.766  73.821    0.043  56.846    0.380 -
56.285
   1.700    0.236 -178.496    9.213  71.086    0.045  56.001    0.369 -
57.740
   1.800    0.238 177.334    8.725  68.404    0.047  54.999    0.358 -
59.199
   1.900    0.241 173.487    8.277  65.836    0.050  53.983    0.348 -
```

```
60.790
   2.000    0.244 169.856    7.874  63.295    0.052  52.923    0.338 -
62.399
   2.200    0.251 162.836    7.172  58.413    0.057  50.729    0.319 -
65.657
   2.400    0.259 156.208    6.578  53.682    0.062  48.414    0.301 -
68.988
   2.600    0.268 150.081    6.068  49.042    0.067  45.958    0.283 -
72.558
   2.800    0.277 144.221    5.628  44.575    0.072  43.380    0.266 -
76.167
   3.000    0.288 138.650    5.244  40.174    0.077  40.713    0.248 -
80.054
   3.500    0.319 125.843    4.470  29.452    0.090  33.634    0.204 -
90.648
   4.000    0.352 113.999    3.873  18.944    0.102  26.177    0.158 -
103.541
   4.500    0.389 103.406    3.406   8.713    0.113  18.415    0.113 -
121.590
   5.000    0.431  92.903    3.011  -1.792    0.123   9.782    0.071 -
156.899
   5.500    0.463  82.559    2.658 -11.364    0.131   2.534    0.054 148.652
   6.000    0.506  73.164    2.374 -21.684    0.138  -6.413    0.095 100.575
   6.500    0.516  66.705    2.179 -28.681    0.152 -10.089    0.112  92.309
   7.000    0.551  59.664    2.011 -37.894    0.164 -17.920    0.164  82.321
   7.500    0.610  50.773    1.808 -49.313    0.166 -29.630    0.246  65.957
   8.000    0.644  43.502    1.653 -58.585    0.172 -37.580    0.300  56.971
   8.500    0.683  35.816    1.496 -68.478    0.175 -46.984    0.361  47.167
   9.000    0.709  27.972    1.338 -77.310    0.173 -55.176    0.412  37.289
   9.500    0.736  20.858    1.212 -85.841    0.172 -63.448    0.449  29.117
  10.000    0.764  14.187    1.105 -95.600    0.173 -72.751    0.505  22.602
  10.500    0.785   7.330    0.997 -104.961    0.171 -81.774    0.554  14.956
  11.000    0.802   0.219    0.884 -113.744    0.164 -91.275    0.593   6.422
  11.500    0.815  -6.751    0.791 -122.965    0.158 -100.952    0.631  -
0.521
  12.000    0.822 -13.843    0.690 -131.882    0.149 -111.108    0.667  -
8.548
!     DEEMBEDDED NOISE DATA
!FREQUENCY    FMIN    GAMMA OPT        Rn
!  (GHz)      (dB)    Mag    Ang   (NORMALIZED)
```

Using these parameter, we shoul compare on the sample display the modelised results and the measurements results, or directly show the error using equations. First we compare the results.

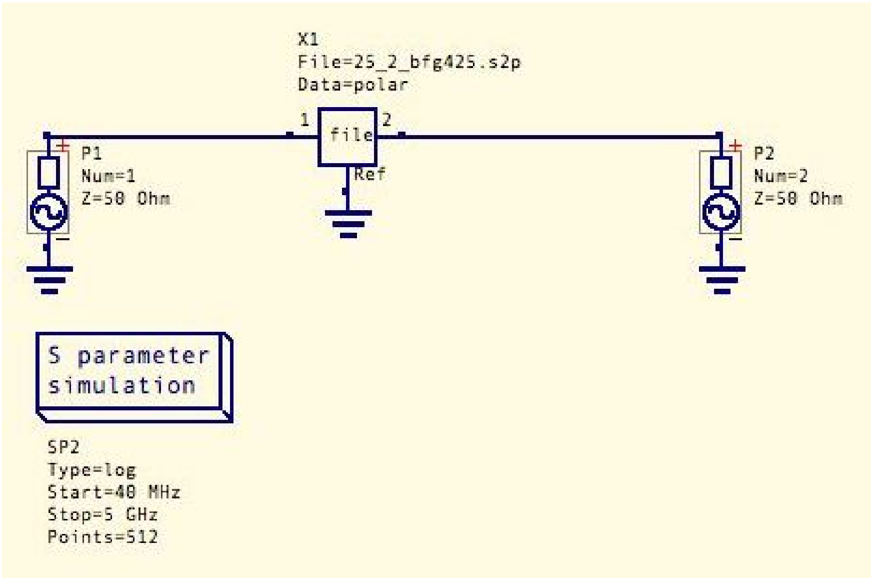


Figure 11: schematics used for S parameters from manufacturer

In the display that is used for the S parameters that we have simulated from our modelisation, you can add the results from the meaurements files by adding a measurement of $S_{i,j}$ using the right dataset with the combo box. You should obtain the difference between the two.
By doing this, you should obtain the results presented in the figure 12.

IMPORTANT NOTE : The differences, you should obtain are still on investigation for now.

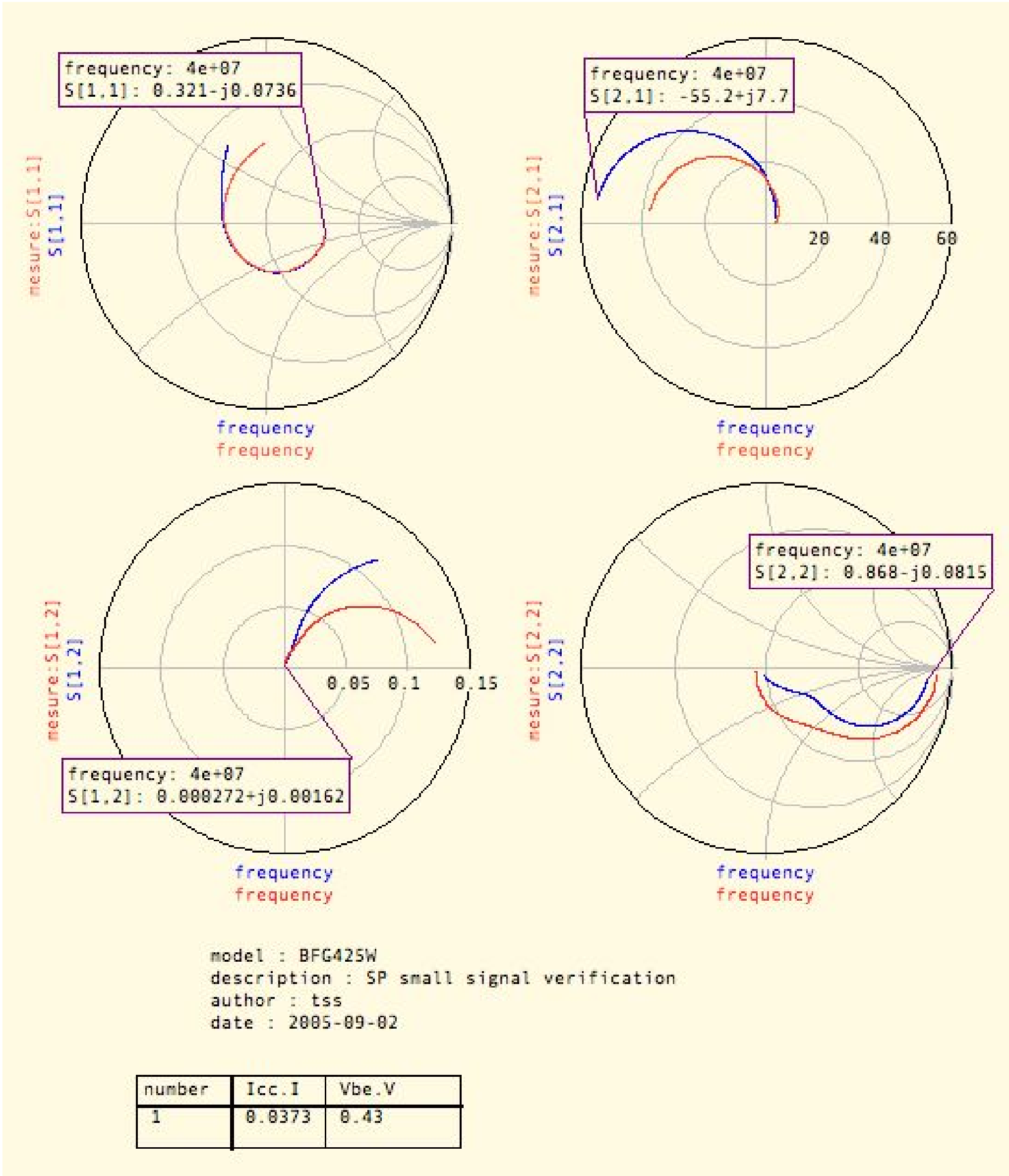


Figure 12: Results from model and from meaures compared together