LNA Matching Example for AD6548

1. Overview

The following application note describes the techniques used for matching of the AD6548 LNA to the RF input SAW filters. As with any RF system matching is key to achieving optimum sensitivity performance of the receiver. The ADI reference board provides the matching for that particular layout and component selection. The customer will only need to re-match if the layout, or component section is different from the ADI reference design. The procedure is quite straightforward, as the matching structures are reduced to only 3 components per band. The only variation will be in the component value. However specialized equipment and RF knowledge is required.

A two stage approach is taken the First stage is to calculate the theoretical values for the matching components. The second stage is to measure the parasitics and then to fine tune the network components values based on the parasitics of the implementation.

2. Equipment List

The following is a list of equipment that is required for the procedure, along with commonly available models and manufactures. Other Models or manufactures may be used if the functionality is suitable.

#	Description	Manufacture	Model # / Distributor
1	Smith Chart plotting PC Software	EEZ Match	Besser Associates
2	S Parameter Network Analyzer (2 GHz min)	Agilent	8753ES
3	High Quality Cables (Precision 7mm to SMA)	Suhner	SucoFlex 104A
4	SMA (3.5mm) Calibration kit	Agilent	85033D
5	GSM Radio Tester	Rohde & Schwarz	CMU200
6	Capacitor Lab design kit 0.5 – 350 pf 0402 size	Murata	GMR Series
7	Chip Inductor sample kit 1 – 100 nH 0402 size	Panasonic	RF Series

3. Worked Example

The following worked example describes the technique required for matching the AD6548 front end to a SAW filter. In the example the theoretical calculations use values obtained from the data sheets. In reality the parasitics, and non ideal components will affect the final values. The technique is however identical, and the mathematics can be applied to the real case when the designer measures the parasitics and uses non ideal component models. Measurement of the parasitics is also described in this guide, as this is essential in a real life application. In actuality there are several methods & combinations that achieve the same result, but the key to success is to ensure that consistency of method is applied to all the steps.

3.1 Theoretical calculations

A seven step process is used to obtain the theoretical match. A spreadsheet program is also provided to incorporate several of the steps. The steps are also described so the designer can get an understanding of the procedure. They are as follows:

1. Calculate the Singled Ended LNA Impedance, from the Data sheet values
2. Obtain the desired Single Ended Load impedance (or Admittance) from the SAW Data sheet.
3. Normalize the values to the preferred reference

4. Place the LNA Impedance on the Smith Chart
5. Using reactive element series + shunt elements move to the LNA impedance around the Smith chart until we achieve the point of the desired Load Impedance for the SAW filter. The SAW will now be matched.
6. Calculate the differential values for the elements indicated by step 5.
7. Obtain actual data for components including non ideals (S parameter Data) and measure parasitics for the board layout, then recalculate the components values, or trim the values to give the best noise figure and VSWR.

Let us now describe each step in more detail:

1) Calculate the Singled Ended LNA Impedance, from the Data sheet values

Let us go to the AD6548 an in the Specification section for the Receiver we see the Input Impedance is a line item for both the Low band and High bands:

Band	Input Impedance	Units	Comments
850 & EGSM	85-J110	Ω	Differential
DCS1800	50-J65	Ω	Differential
PCS1900	70-J75	Ω	Differential

So the two points to note here are that this is a measure of the **differential Impedance**. Thus the circuit model looks like a resistor in series with a reactive element. For the 850 & EGSM case the real part (resistance) is 85 Ohms and the imaginary (Capacitance, as negative) part is 110 Ohms. As discussed before we need to obtain the single ended version. However as we are working in terms of Reactance (not Capacitance) the conversion is very simple, as demonstrated below:

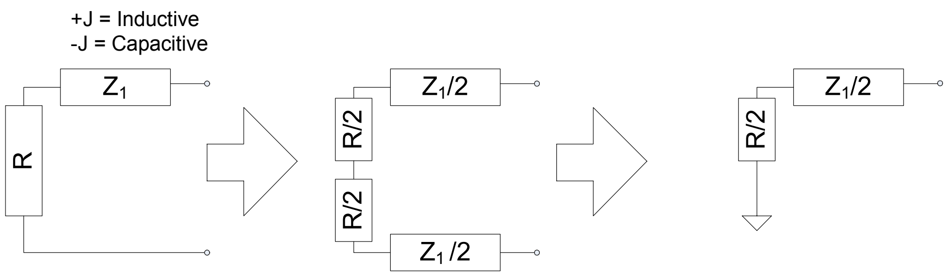
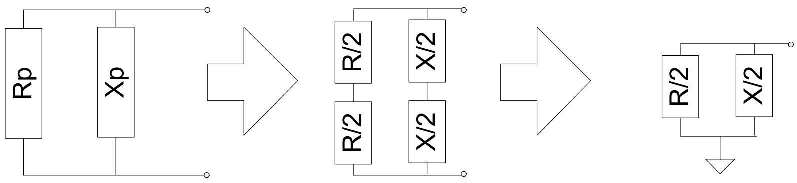


Figure 1: Series circuit conversion to single ended equivalent

So to summarize; both elements of Input impedance given in the data sheet should be halved to give the single ended equivalent.

2) Obtain the desired Single Ended Load impedance (or Admittance) from the SAW Data sheet

The manufactures data for the SAW device should specify what is the desired load for the SAW filter. This will typically be a differential specification, and is normally about 150 Ohms with a shunt reactive component. Normally this is an Inductor, as the SAW itself is capacitive, so an Inductor is needed to tune out this parasitic effect. If the equivalent circuit is specified we need to calculate the Impedance (or Admittance), for Normalization and plotting the correct point on the Smith chart. This is easy to do, and at the same time we can convert to the singled ended model. One note of caution: If the circuit is in the parallel form, which typically it its, we either should convert this to the series equivalent, or remember this fact and use the Admittance Smith chart for this point. Using the Admittance Smith chart is the simplest way, as this requires no computation, and it perfectly legal, but just remember this point.



Xp = 2πfL if Xp is an inductance;

Xp = $\frac{1}{2\pi fC}$ if Xp is a capacitance.

Figure 2: Parallel circuit conversion

So using the above formula the imaginary component can be calculated for the frequency of interest. We now have both the actual load and desired load in terms of impedance. However one is a series equivalent circuit and one is parallel, but that is OK as discussed.

For a practical example we can use the Murata SAFEK881MFL0T00R00, which sates the Load Impedance required is 150 Ohm // 82 nH. This is for the 850 MHz GSM band so lets choose the centre of the RX band as the frequency of interest: 881 MHz.

So this is a shut inductance:

$X = \pi\ 881 \times 10^{6} \times 82 \times 10^{-9}$

= 227 Ohms.

R = 150 / 2

= 75 Ohms

3) Normalize the values to the preferred reference

Generally the smith chart is normalized to 50 Ohms. That is 50 Ohms is in the centre of the chart and is equal to 1 on the chart scales. This is ideal for a typical 50 Ohm system, However the chart can be normalized to any value. We see that the real part of our ideal load is actually 75R so we can choose this as our normalization factor. Generally this can be selected in smith chart software setup menu. So as all values we have are presently impedance they should be divided by the factor:

	Actual	Normalized To 75R	Admittance
Load Real	42.5	0.57	
Load Imaginary	55	0.73	
Desired Real	75	1	1
Desired Imaginary	227	3.03	0.33

For simplicity steps 1 through 3 are designed into a spreadsheet tool that can be provided to the customer. The Output is shown below for our case study:

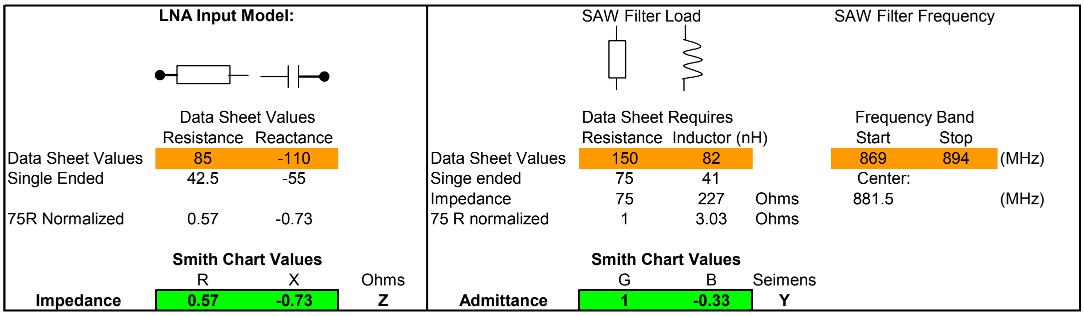


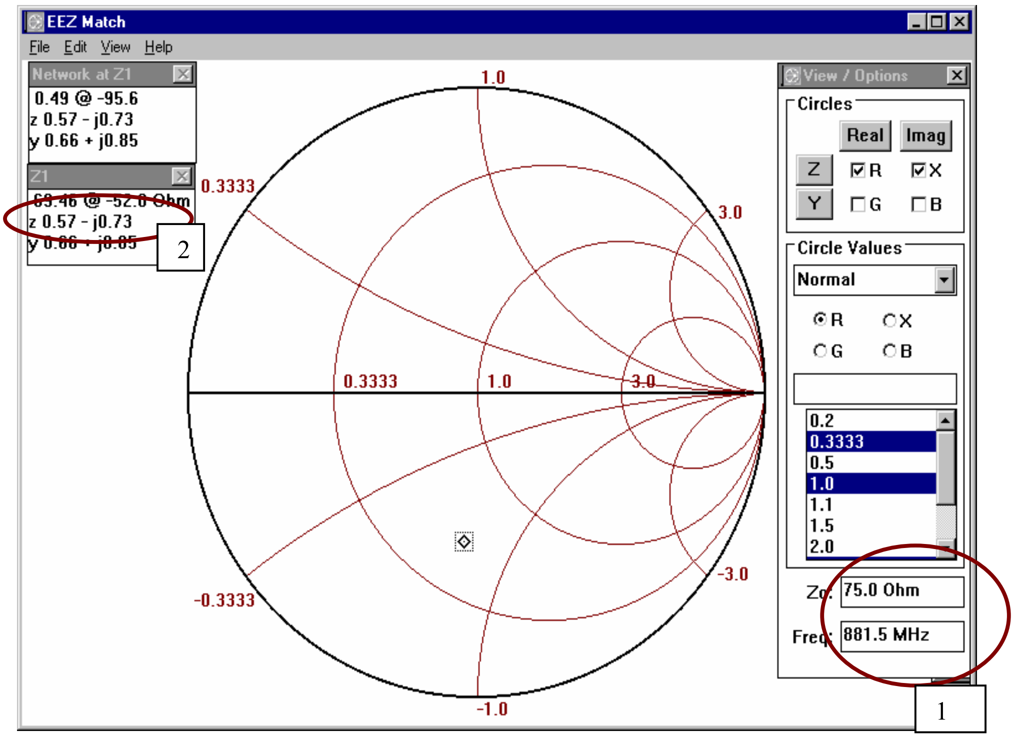
Figure 3: Spreadsheet Output for Smith Chart Values

The inputs are shown in Orange and the outputs in green. The frequency band is set for 850 MHz Receive, as per the Saw data sheet, and the centre frequency calculated.

4) Place the LNA Impedance on the Smith Chart

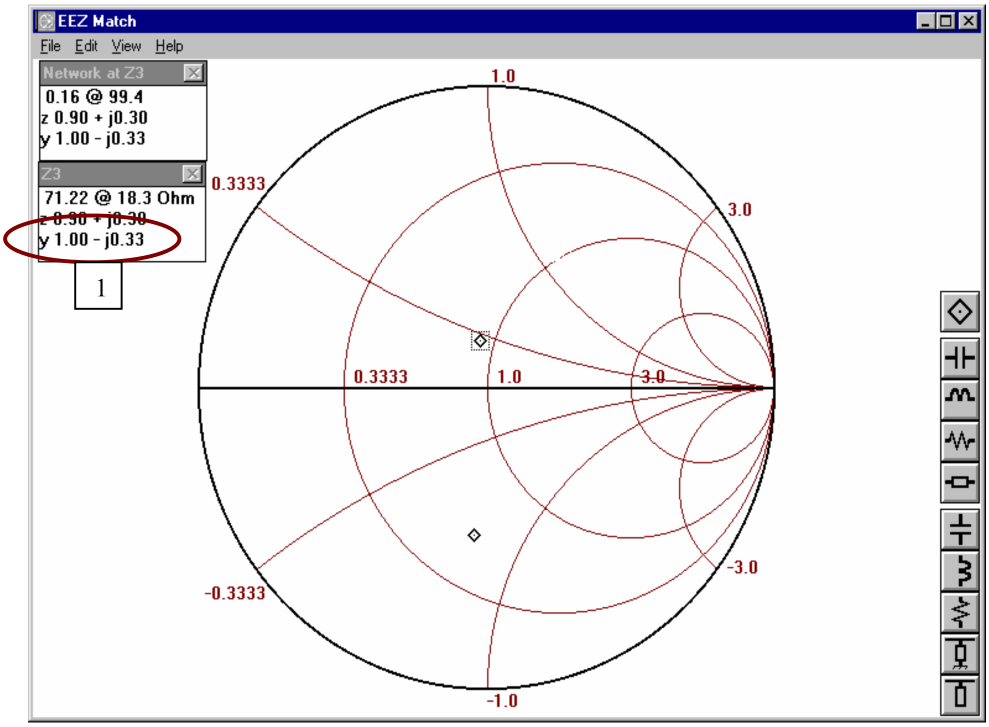
So now what we need to do is to present a load to the SAW that is correct. When we “Look Into” the LNA input we see 0.57-J0.73. By using reactive components we can make look like the correct load: Remember we are always looking into what is in effect the SAW load. As we build the network we are moving away from the LNA inputs, towards the SAW filter. We stop adding components when we achieve the desired SAW load. The best tool for this is the Smith chart. Many RF programs have capabilities to display Smith Charts. One such tool is EEZ Match which has basic functionality, but suitable for this exercise.

The LNA Input is placed on the Smith chart as the starting point for our network. We have normalized impedance values for the series network so the values in the above table represent the correct point on the Smith Chart. As the real part is lower than the normalized real impedance and is also capacitive we should expect this point to be in the lower left had part of the chart.



1) Ensure that the Parameters are correct in the Setup section
2) Add the starting point: The LNA Load Impedance.

It may also be a good time to add the expected SAW load onto the diagram at the same time. This is our target. However these points **cannot** be directed related to the position on the smith chart quite yet. The problem is we have impedance values, but the model is in the shunt format. A shunt network cannot be represented by R +-JX, without first transforming the impedance values to their series equivalents. This of course is very straightforward, but is another mathematical operation. It is simpler to use the Admittance values for the components we have and then simply remember to plot the position on the Admittance smith chart. This is the way we shall proceed, but both ways are valid. As we have real and imaginary components split up the Admittance is simply the reciprocal of the Resistance to give Conductance and reactance to give Suseptance. As we have normalized to the real part this remains unchanged at 1! The Suseptance is calculated, and now we have the correct values to place on the Smith chart; for our example 1 – J0.33. Note that the inductor sign is a negative for admittance. This point can now be placed on the Smith chart using an Admittance chart superimposed onto the previous Impedance one. This is done in software which gives entry field for both Impedance and Admittance; just be sure to use the right box!!

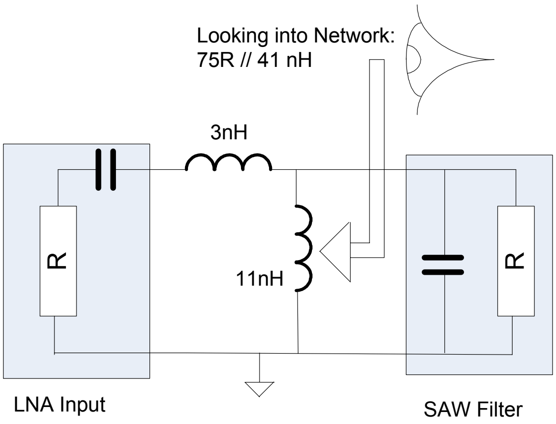


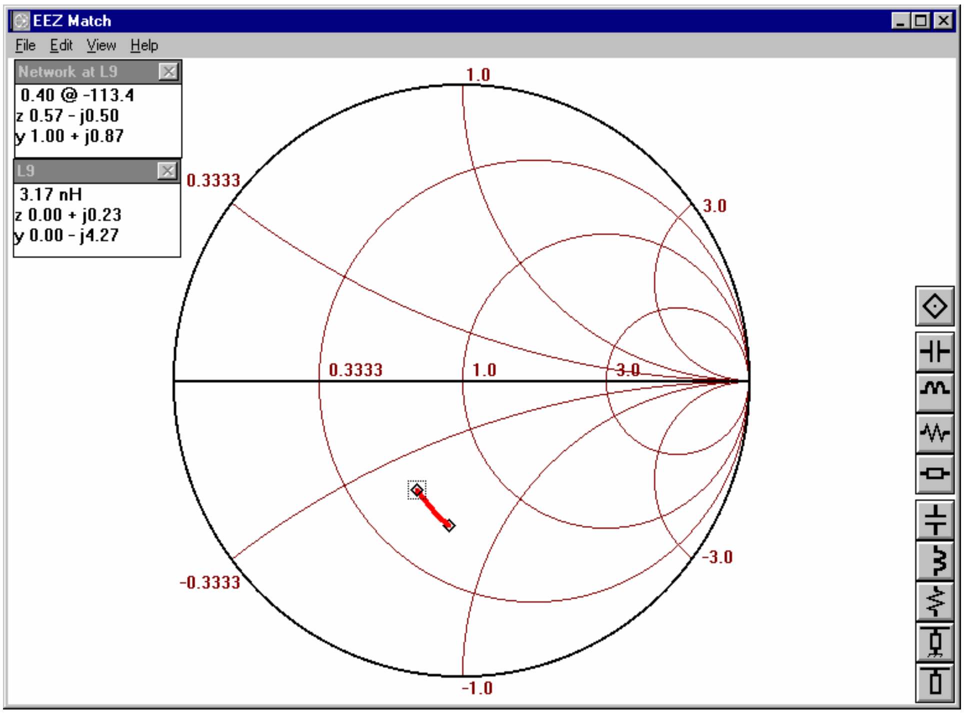
1) Add in the target, don't forget this is **Admittance** (y)!

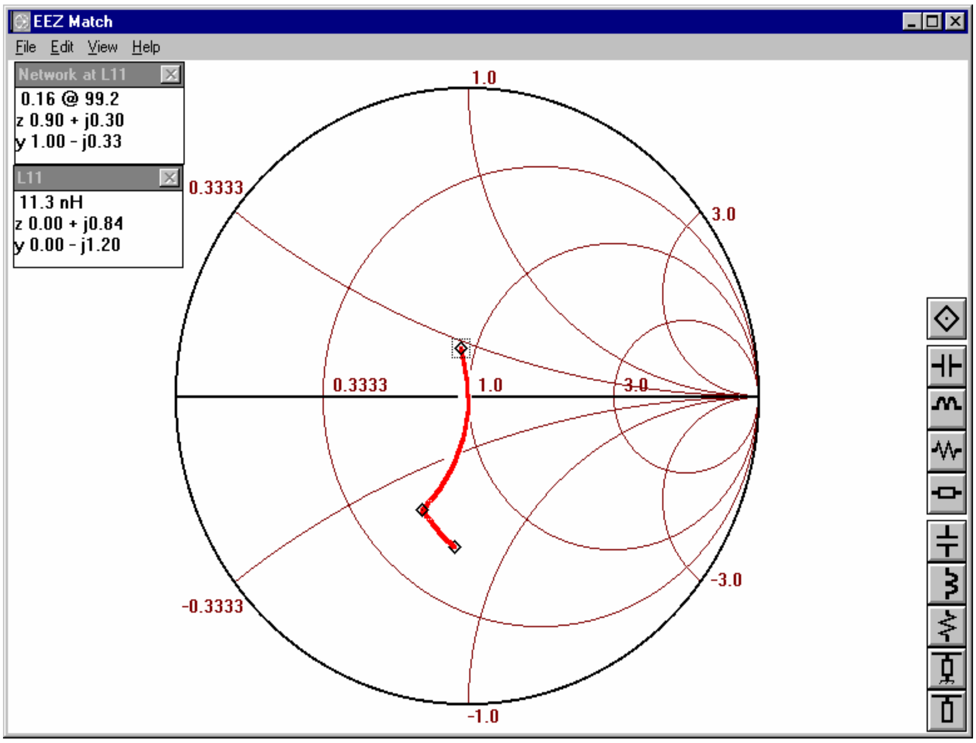
5) Use the Smith chart to build the matching network

The matching network can now be build by adding a series component of the correct magnitude and type to move around the Smith chart such that we are on the circle that intersects with the centre of the chart. Once we are on that circle we can add a shut inductor to bring us through the origin to the desired load point that we plotted. Once complete we can then read the component values from the software. Be sure that the frequency is set correctly in the Setup menu, otherwise the components values will be wrong.

In our example of the GSM850 band we need to add a series inductor. Until the network admittance is 1. The software is interactive and so the value can be dynamically adjusted until the correct result is achieved. The node, L9 in this case, even shows us the component value, (3.17nH) as shown in the first diagram below. This now puts us in the perfect position to add the shut inductor to complete the network match. The second diagram shows the addition of the shunt Inductor to complete the network. We are now at our goal of Y = 1 –J0.33. Again the component value can be read off the software display, 11.3 nH. So now we have a complete single ended representation of the desired network, For our case study the diagram is shown below:

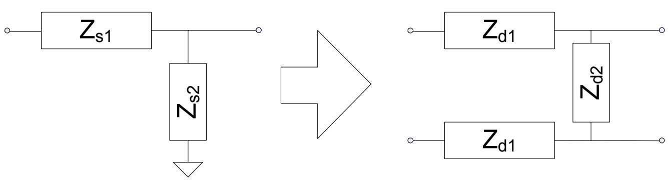






6) Calculate the differential values for the elements indicated by step 5.

We have to remember that we are in single ended mode. The final network is differential, so we need to convert the values, but this is very straightforward:

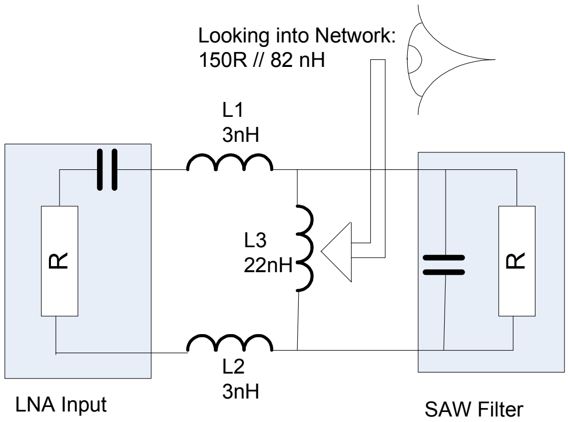


$Z_{d1} = Z_{s1}$

$Z_{d2} = 2 \times Z_{s2}$ If the Z is an inductor. (This is the normal case)

$Z_{d2} = ½ Z_{s2}$ If the Z is a capacitor. (Generally not the case with a SAW).

So in our worked example we can see the final component values are calculated in the table below.



Also we can see the final values that are used in the circuit, so the discrepancy is because of the non ideal components and parasitics. The next section describes how the actual values can be measured using a Network analyzer.

Component	Single ended value	Calculated Final Value	Actual Value
L1, L2	3 nH	3 nH	2.2 nH
L3	11 nH	22 nH	18 nH

3.2 Practical Method

In the entire transceiver subsystem the match between the antenna port and the switch may need to be considered, as well as the match to the AD6548. If the switch is changed from the ADI reference design this will have to be considered also. Once the fully front end match is completed the match can be verified using the BER measurements.

Figure 1 shows the receive path for reference.

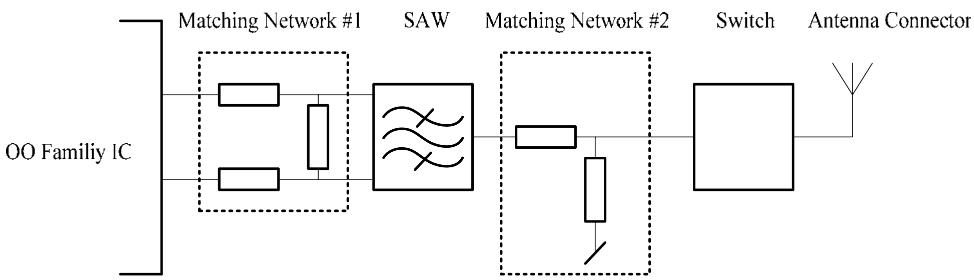


Figure 1. Receive path showing placement of matching networks.

3.2.1 Matching Single Ended side of SAW

The first step is to get a proper match between the SAW and Switch.

To get the right frequency response the SAW must be loaded with the loading specified in the datasheet. Therefore SAW is disconnected from the IC and loaded with the proper loading – it should be possible to use the pads already there. To take parasitic from the PCB/components into account, the loading should be trimmed by stepping one value step up/down until the best loading is achieved; this is verified by minimizing the loading circle on the Net Work Analyzer (NWA).

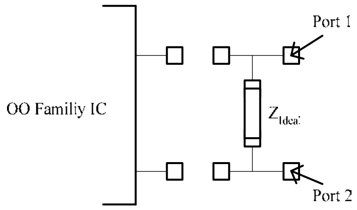
The Net Work Analyzer is connected to the antenna connector and port extended to the first matching component. The “Matching Network #2” is trimmed to 50 Ohm.

3.2.2 Matching balanced side of SAW

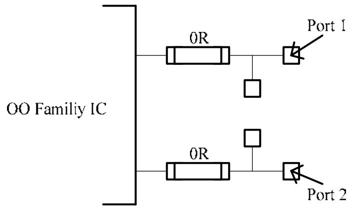
The next step is to develop the matching between the IC and the SAW. There are numerous ways in achieving this, either by simulation, by calculations or by measurements, both simulations and calculations should be based on S-parameter files from the supplier of the SAW and Analog Devices. Or even better based on real S-parameter measurements made directly on the board to be matched.

This section of the Apps note deals with a measurement approach. As the loading of the SAW is already optimized on the PCB, this will be used to avoid having to consider too many parasitics. The SAW is dismounted and probes are placed on the pads of the SAW. Remember to port extent the NWA to the tip of the probes.

Using a two port S parameter measurement the ideal differential loading, Z_{ideal}, is measured. See figure X. The conversion of two port S parameters into differential impedance is shown in Appendix B



The loading is removed and 0 Ohm resistors are placed on the series pads, see figure Xx. The IC is put into continuous receive mode and the differential input impedance is matched to Z_{Ideal}. As the impedance is differential the two port S parameters need to be converted each time. Also remember when using the smith chart, the values has to be recalculated into differential values.



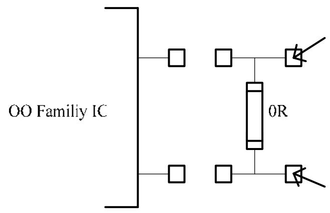
3.2.3 Trimming the match

Initial matching networks on both sides of the SAW have been developed. After remounting the SAW the matches are first verified using the NWA. This is done using same procedure as used when matching the single ended side of the SAW - the size of the loading circle is minimized using Matching Network 1, and the center of the circle is changed using Matching Network 2.

The final verification of the matching is done using an communication tester. The sensitivity is found. If further trimming is desired the values of the matching components can be stepped up/down one value and measuring sensitivity for each step.

4. Appendix

4.1 Transforming measured values between Single ended and differential



One way to convert the S-parameters is to use an ideal balun in a simulation program. Alternatively the transformation can be done by hand e.g by transforming the S-parameters to Z-parameters and make a equivalent T-network to find the balanced impedance (See e.g. Pozar p.237)

$Z_{Bal} = Z_{11} - Z_{12} + Z_{22} - Z_{21}$

When the 2-port impedance is transformed into a balanced impedance the balanced impedance can be treated as a normal one-port impedance in the smith chart. Once the match has been found here the matching values has to be translated into real values for the balanced matching circuit.

Shunt components keep their value whereas the series elements is split up into two components so that the series connection of the two components will have the same value as the balanced matching component e.g. $C_{Match} = 2*C_{Balanced}$ and $L_{Match} = 1/2*L_{Balanced}$

4.2 Port extension

The measurement cables to connect to the SAW pads could be e.g. thin semi rigid cables. It is important to keep these cables short and make sure they are grounded at the end as close to the tip as possible. It is a good idea to ground them further away from the tip as well to make the setup more mechanical stable.

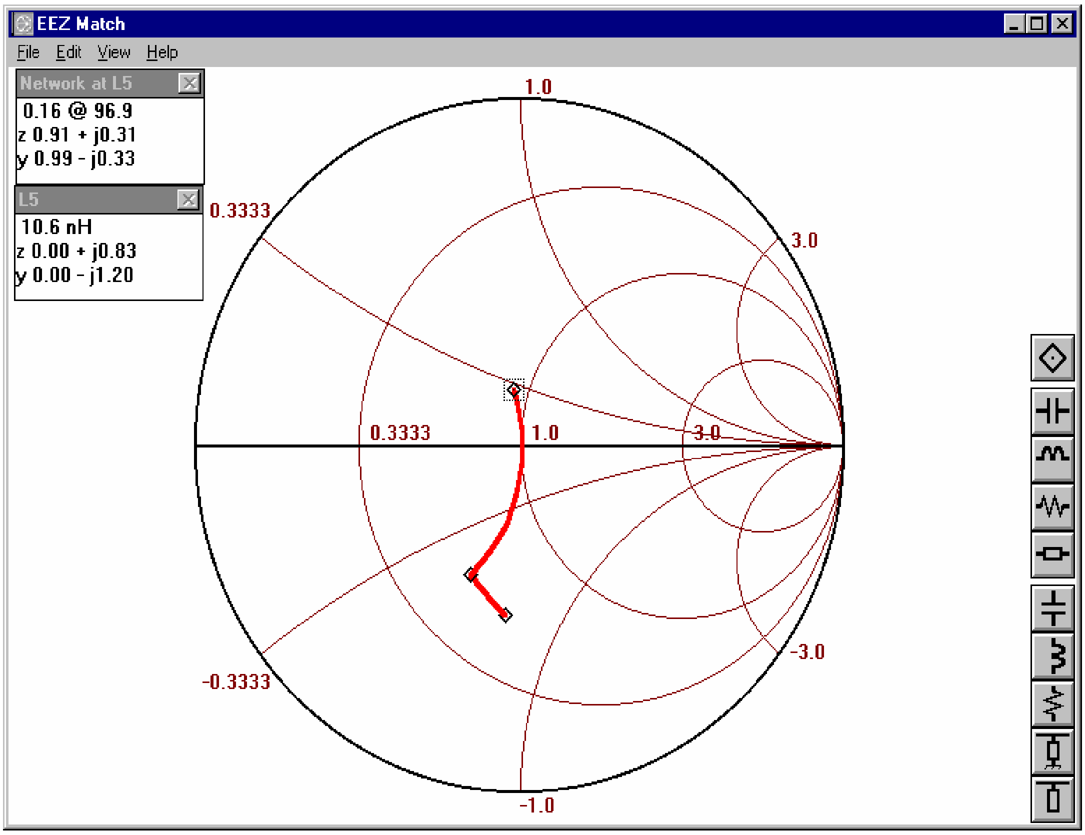
For the port extension it is important to check the extension both with the ports short to gnd and open and choose an extension as a compromise in between. This also gives an idea of the accuracy you can get with this setup.

4.3 Theoretical Matching Examples for each band

4.3.1 EGSM Band

EGSM

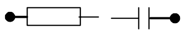
	LNA Input Model:				SAW Filter Load			SAW Filter Frequency		
	Data Sheet Values				Data Sheet Requires			Frequency Band		
	Resistance	Reactance			Resistance	Inductor (nH)		Start	Stop	
Data Sheet Values	85	-110		Data Sheet Values	150	82		869	894	(MHz)
Single Ended	42.5	-55		Singe ended	75	41		Center:		
				Impedance	75	227	Ohms	881.5		(MHz)
75R Normalized	0.57	-0.73		75 R normalized	1	3.03	Ohms			
	Smith Chart Values				**Smith Chart Values**					
	R	X	Ohms		G	B	Seimens			
Impedance	**0.57**	**-0.73**	**Z**	**Admittance**	**1**	**-0.33**	**Y**			



4.3.2 DCS Band

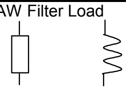
DCS1800

LNA Input Model:



	Data Sheet Values		
	Resistance	Reactance	
Data Sheet Values	50	-65	
Single Ended	25	-32.5	
75R Normalized	0.33	-0.43	
	Smith Chart Values		
	R	X	Ohms
Impedance	0.33	-0.43	**Z**

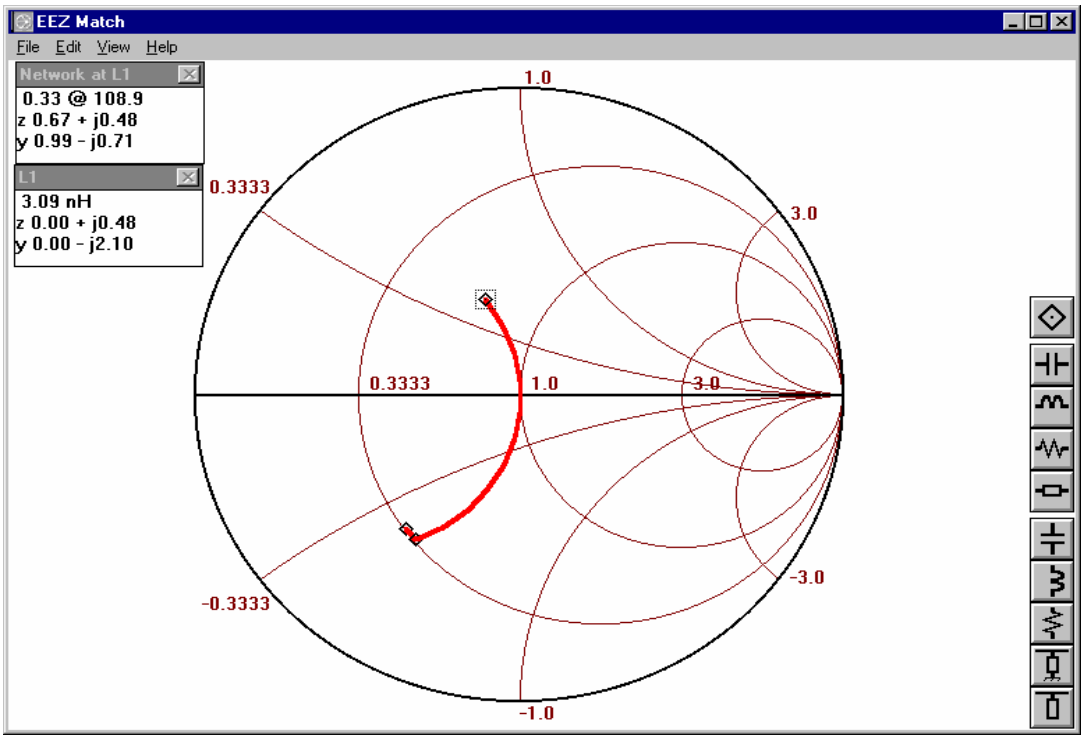
SAW Filter Load



	Data Sheet Requires		
	Resistance	Inductor (nH)	
Data Sheet Values	150	18	
Singe ended	75	9	
Impedance	75	104	Ohms
75 R normalized	1	1.39	Ohms
	Smith Chart Values		
	G	B	Seimens
Admittance	1	-0.72	**Y**

SAW Filter Frequency

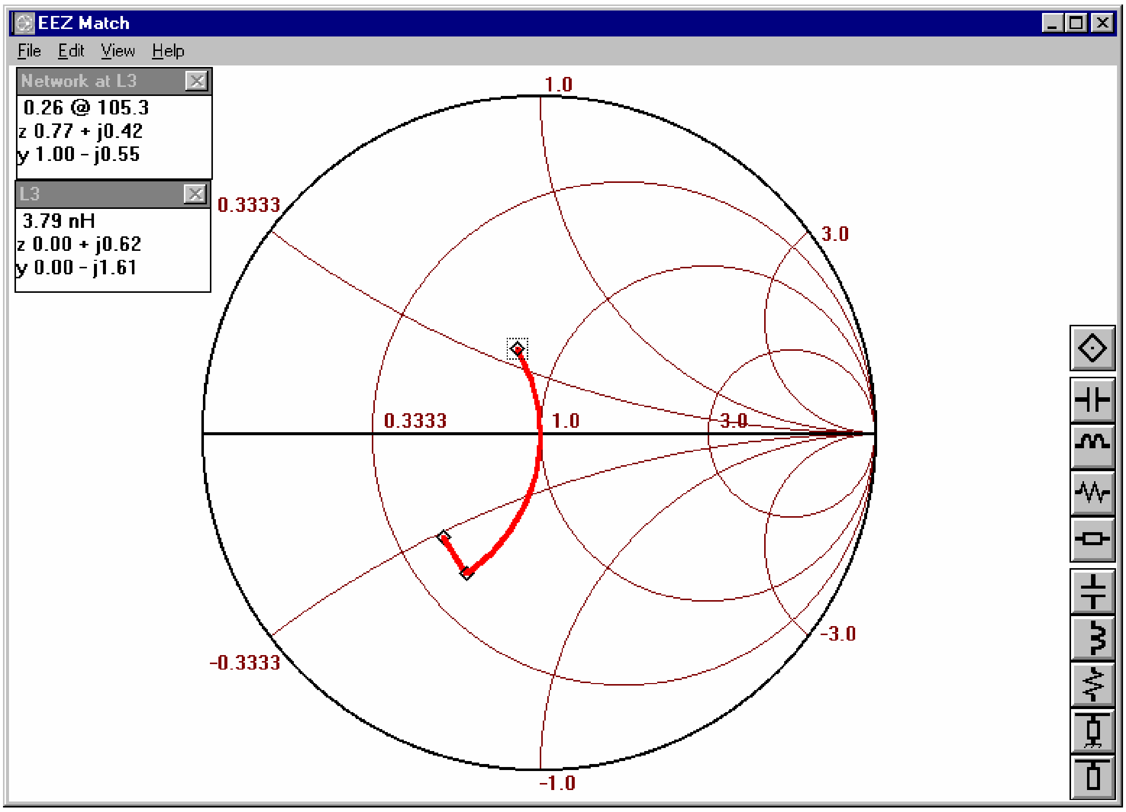
Frequency Band		
Start	Stop	
1805	1880	(MHz)
Center:		
1842.5		(MHz)



4.3.3 PCS Band

PCS1900

	LNA Input Model:				SAW Filter Load			SAW Filter Frequency		
	Data Sheet Values				Data Sheet Requires			Frequency Band		
	Resistance	Reactance			Resistance	Inductor (nH)		Start	Stop	
Data Sheet Values	70	-75		Data Sheet Values	150	22		1930	1990	(MHz)
Single Ended	35	-37.5		Singe ended	75	11		Center:		
				Impedance	75	135	Ohms	1960		(MHz)
75R Normalized	0.47	-0.50		75 R normalized	1	1.81	Ohms			
	Smith Chart Values				**Smith Chart Values**					
	R	X	Ohms		G	B	Seimens			
Impedance	**0.47**	**-0.50**	**Z**	**Admittance**	**1**	**-0.55**	**Y**			



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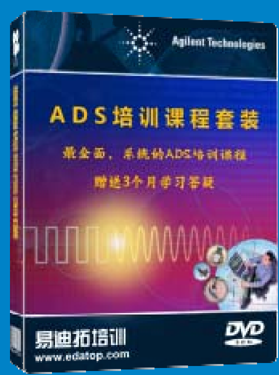

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课程网址：http://www.edatop.com/peixun/hfss/11.html

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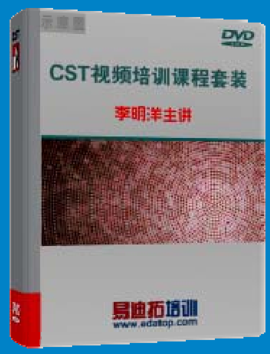

该培训套装由易迪拓培训联合微波 EDA 网共同推出，是最全面、系统、专业的 CST 微波工作室培训课程套装，所有课程都由经验丰富的专家授课，视频教学，可以帮助您从零开始，全面系统地学习 CST 微波工作的各项功能及其在微波射频、天线设计等领域的设计应用。且购买该套装，还可超值赠送 3 个月免费学习答疑…

课程网址：http://www.edatop.com/peixun/cst/24.html

HFSS 天线设计培训课程套装

套装包含 6 门视频课程和 1 本图书，课程从基础讲起，内容由浅入深，理论介绍和实际操作讲解相结合，全面系统的讲解了 HFSS 天线设计的全过程。是国内最全面、最专业的 HFSS 天线设计课程，可以帮助您快速学习掌握如何使用 HFSS 设计天线，让天线设计不再难…

课程网址：http://www.edatop.com/peixun/hfss/122.html

13.56MHz NFC/RFID 线圈天线设计培训课程套装

套装包含 4 门视频培训课程，培训将 13.56MHz 线圈天线设计原理和仿真设计实践相结合，全面系统地讲解了 13.56MHz 线圈天线的工作原理、设计方法、设计考量以及使用 HFSS 和 CST 仿真分析线圈天线的具体操作，同时还介绍了 13.56MHz 线圈天线匹配电路的设计和调试。通过该套课程的学习，可以帮助您快速学习掌握 13.56MHz 线圈天线及其匹配电路的原理、设计和调试…

详情浏览：http://www.edatop.com/peixun/antenna/116.html

我们的课程优势：

※ 成立于 2004 年，10 多年丰富的行业经验，

※ 一直致力并专注于微波射频和天线设计工程师的培养，更了解该行业对人才的要求

※ 经验丰富的一线资深工程师讲授，结合实际工程案例，直观、实用、易学

联系我们：

※ 易迪拓培训官网：http://www.edatop.com

※ 微波 EDA 网：http://www.mweda.com

※ 官方淘宝店：http://shop36920890.taobao.com