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Application Note SAW Components

Matching of front-end SAW filters to integrated RKE receivers

App. Note #18

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Introduction

For RKE systems “single-chip” receivers and “single-chip” transceivers are used. For the matching proposals we take the TDA520x series from INFINEON and the ATA572x series from ATMEL as example.

To improve the selectivity and the image frequency rejection of the system a SAW front-end filter should be placed between antenna and the receiver. Furthermore, the problem of receiver blocking by powerful out-of-band interfering signals is strongly reduced. Narrow-band front-end SAW filters are available for all frequency ranges in use.

The front-end of RKE receivers

The basic structure of a receiver or of the receive path of a transceiver is realised with a “superheterodyne approach”, built of a low-noise amplifier (LNA) and a mixer. Depending on the receiver integrated circuit (Rx IC) the frequency of the local oscillator LO is defined in such a way that the output signal of the mixer has an intermediate frequency of some MHz or a few hundred kHz. This intermediate signal can be handled by the demodulator.
A typical front-end of a RKE system is shown in Figure 1:

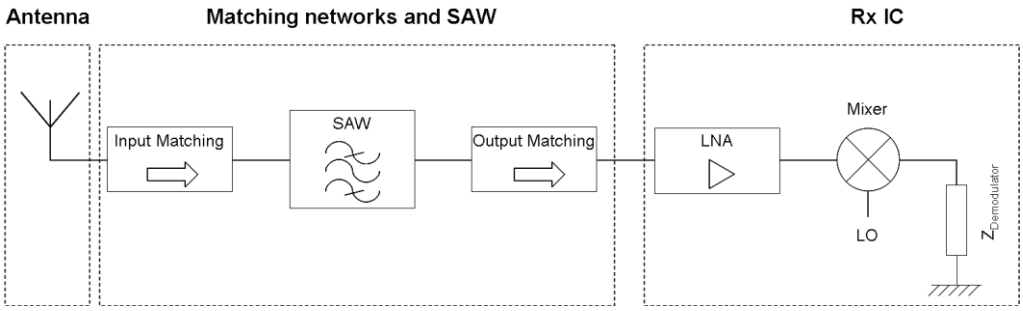


Figure 1: Front-end of a RKE receiver path

A SAW filter offers the following benefits: a low insertion loss, a very high selectivity, blocking of the image frequency and blocking of interfering signals. If the input of a Rx IC is differential, customized SAW filters can provide the balun function as well.

Antenna

The typical antenna impedance of a quarter lambda whip antenna is in the range of 50 Ω. The exact input matching of the SAW filter depends on the characteristic antenna impedance.

A test point, like presented in Figure 2, simplifies the verification of the input and output matching networks.

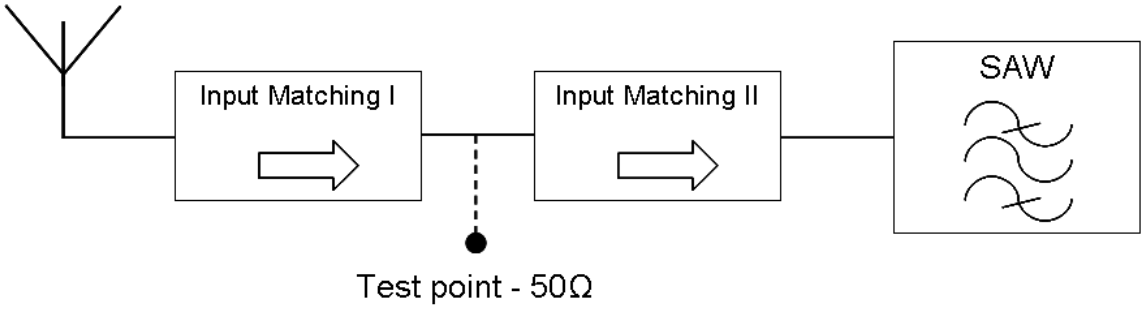


Figure 2: Antenna test point

In the following it is supposed that the antenna impedance is 50 Ω.

Matching networks and SAW

Narrow-band front-end SAW filters have input and output impedances different from 50 Ω. Narrow band front-end SAW filters are designed for power matching. Power matched SAW filters provide a flat pass-band and a low insertion loss.

Power matching

Power matching means that the maximum of the power at the source, e.g. the antenna, is transferred to the load, e.g. the input port of a SAW filter.

This is the case if the source impedance $Z_{source} = R_{source} + jX_{source}$ sees its complex conjugate counterpart $Z^* = R_{source} - jX_{source}$.

$$P_{load} = I_{rms}^2 \cdot R_{load} = \frac{1}{2}|I|^2 \cdot R_{load} = \frac{1}{2}\left(\frac{|V_{peak}|}{|Z_{source} + Z_{load}|}\right)^2 \cdot R_{load} = \frac{1}{2} \cdot \frac{|V_{peak}|^2}{(R_{source} + R_{load})^2 + (X_{source} + X_{load})^2} R_{load}$$

$$\max(P_{load}) = \frac{|V_{peak}|^2}{8 \cdot R_{load}} \text{ , if } R_{load} = R_{source} \cup X_{load} = -X_{source}$$

A general example is given in Figure 3.

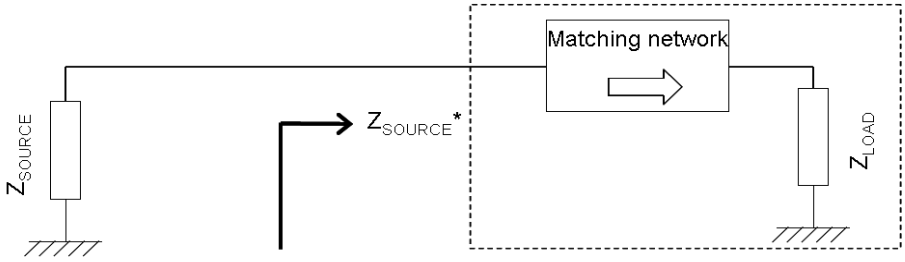


Figure 3: Power matching

A matching network transfers the load impedance to Z*.

Direct and 2 steps matching
The matching between the SAW filter and the Rx IC can be done directly or in two steps. In two steps means a first matching network transforms the impedance from one component to 50 Ω and then another matching network realises the transformation from 50 Ω to the complex conjugate impedance of the following component, e.g. the internal LNA of the Rx IC (Figure 4).

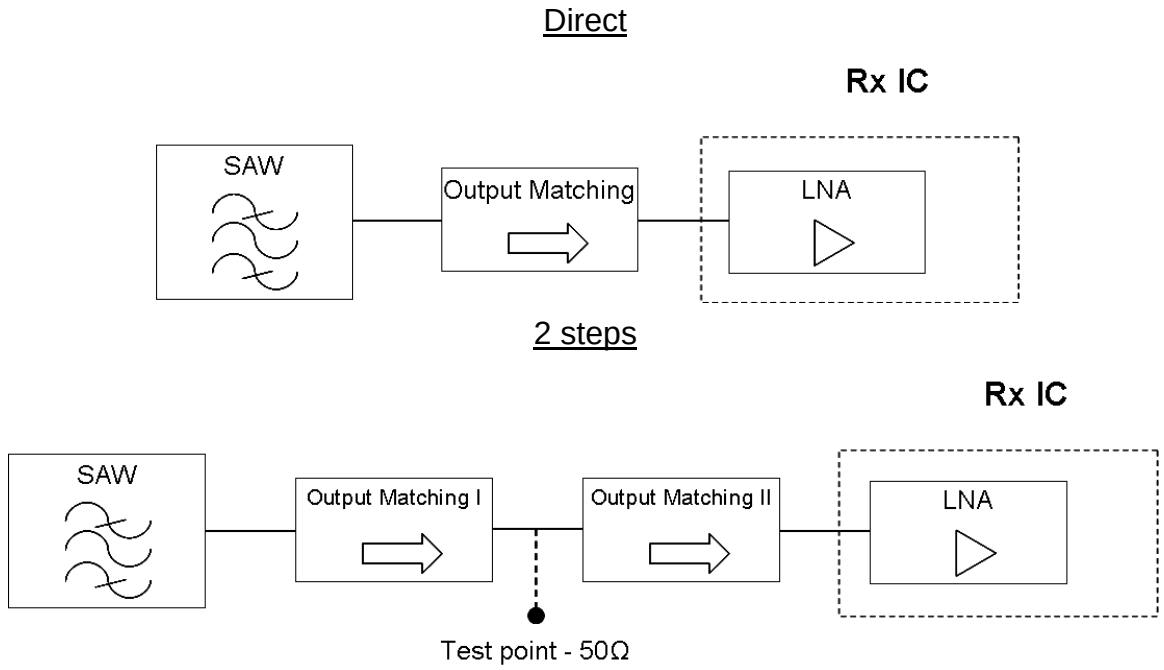


Figure 4: Matching options, direct and 2 steps matching

Matching	Advantages	Disadvantage
direct	• lower losses in matching networks • less components in matching networks	• only overall performance measurable (e.g. input matching, SAW filter, output matching, LNA)
2 steps	• 50 Ω environment test points possible	• higher losses in matching networks • more components in matching networks • less stable due to a longer transformation path in the Smith chart

Table 1: Advantages and disadvantages of direct and 2 steps matching

LNA
The internal LNA of the Rx IC is used to amplify the received signal, so that the signal power at the demodulator offers sufficient strength. However, not only the signal power is important. A high signal to noise ratio is crucial to avoid errors during the transmission of the data. That is the reason why the noise behaviour of the LNA must also be controlled.

Maximum gain matching vs. optimum noise matching
Every amplifier at a certain operating point has a specific impedance for maximum gain, which is used for power matching, and a specific impedance for optimum noise, which is used for noise matching. If these impedances do not coincide, it might happen that for the configuration with the lowest bit error rate the pass-band of the SAW filter shows no optimum flatness.

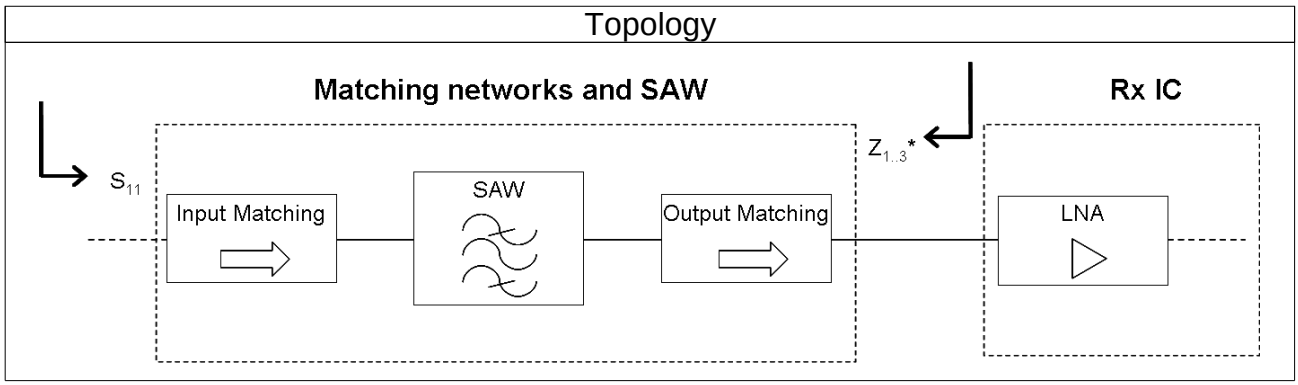


Figure 5: Circuit topology for maximum gain matching vs. optimum noise matching

In the following the focus of our interest in the circuit topology lies in the interface of the output matching network of the SAW filter and the LNA of the Rx IC.

The matching of this interface is indicated by the S_{11} of the input matching network of the SAW filter. S_{11} can be measured with a network analyser.

The input of Rx IC has in the pass-band of SAW filter the impedance Z_1. So for the output matching network, the impedance Z_1* would be the optimum impedance for maximum gain matching of the LNA.
However, if the output matching network shows the impedance Z_3* to the LNA, the LNA generates the minimum noise.
The impedance Z_2* is the best compromise between maximum gain matching and minimum noise matching. For this impedance the signal to noise ratio will be the highest.

One way to quantify the data errors is a sensitivity measurement. Sensitivity measurements are performed with a data-signal generator. The signal power of the signal generator, for which the sent and received data are still identical, is plotted versus the signal frequencies of the signal generator.

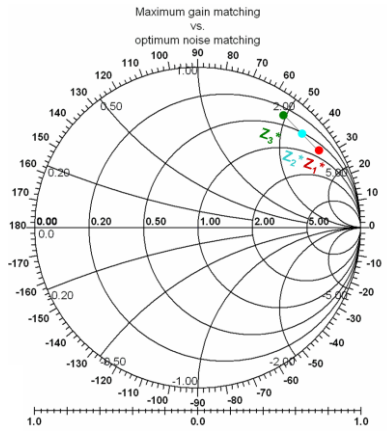
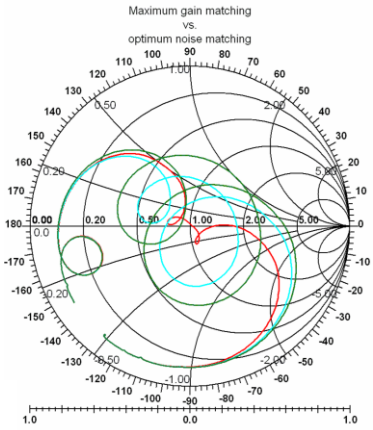
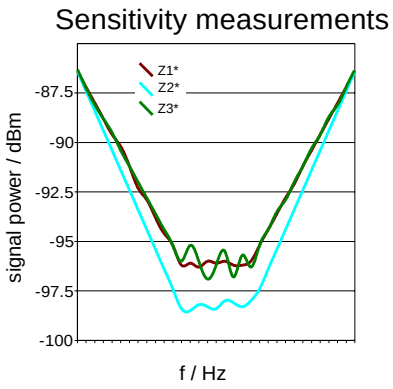
Example of **different** impedances for maximum gain and optimum noise		
Output impedances of the output matching networks	S_{11} at input matching network	Sensitivity
		

Figure 5a: Circuit behaviour in the case of different impedances for maximum gain and optimum noise

For Z_1* as the output impedance of the output matching network S_{11} is curled in the centre of the Smith Chart and the sensitivity level is nearly constant over the whole pass-band. This situation corresponds to an optimum flat pass-band of the SAW filter.
If the output matching network offers Z_3* to the LNA of the Rx IC, then S_{11} is no more located tightly around the centre of the Smith Chart and the pass-band of the SAW filter will not offer optimum flatness anymore. Consequently sensitivity measurements will show a curve with a higher ripple. The sensitivity level is affected favourably by a low noise level and simultaneously it is affected negatively by higher losses in the matching networks.
Therefore the output impedance of the output matching network Z_2* will be the best compromise of these two effects and best sensitivity measurement results will be obtained.

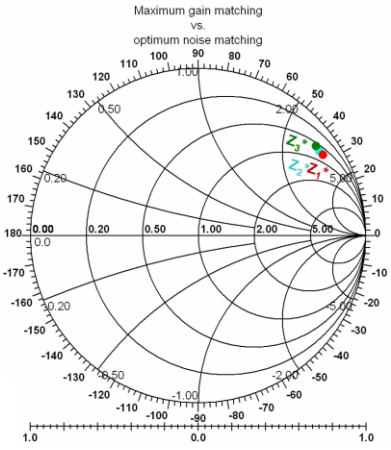
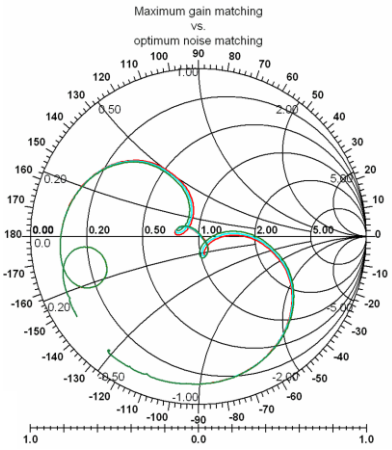
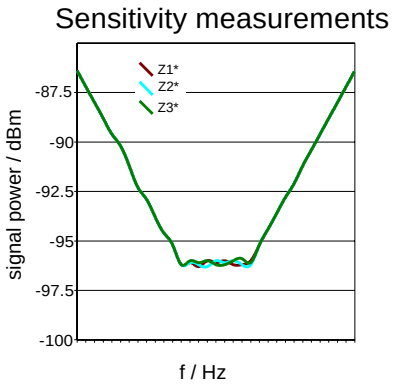
Example of **similar** impedances for maximum gain and optimum noise		
Output impedances of the output matching networks	S_{11} at input matching network	Sensitivity
		

Figure 5b: Circuit behaviour in the case of similar impedances for maximum gain and optimum noise

If the specific impedances for maximum gain and optimum noise are similar, losses in matching networks and the noise level of the LNA of the Rx IC will be similar too. As a consequence the sensitivity measurements for all impedances will be alike as well.

In the case of different impedances, there are two approaches:

- 2 steps matching: The input matching network of the LNA of the Rx IC will be matched to a 50 Ohm test point, so that the highest signal to noise ratio are obtained. Then output matching network of the SAW filter is power matched to the 50 Ohm test point.
- Direct matching: Once the maximum gain impedance is found, the matching elements have to be changed slightly and measuring the sensitivity the optimum matching will be found.

In general, the RF power of the network analyser or the signal generator should be limited to –40dBm so that the LNA works in linear range. If there is an automatic gain control, it should be adjusted to maximum gain.

In the following we will match to the maximum gain impedance.

SAW filter matching

There are several matching structures which offer different benefits. As on each PCB the situation is different and as there are only a limited number of values of the matching components, some matching structures might suite better than others.
For each design the matching must be optimized.

High and low pass configurations are presented in Figure 6. In Figure 7 we see that there are notable differences in the wide band view.

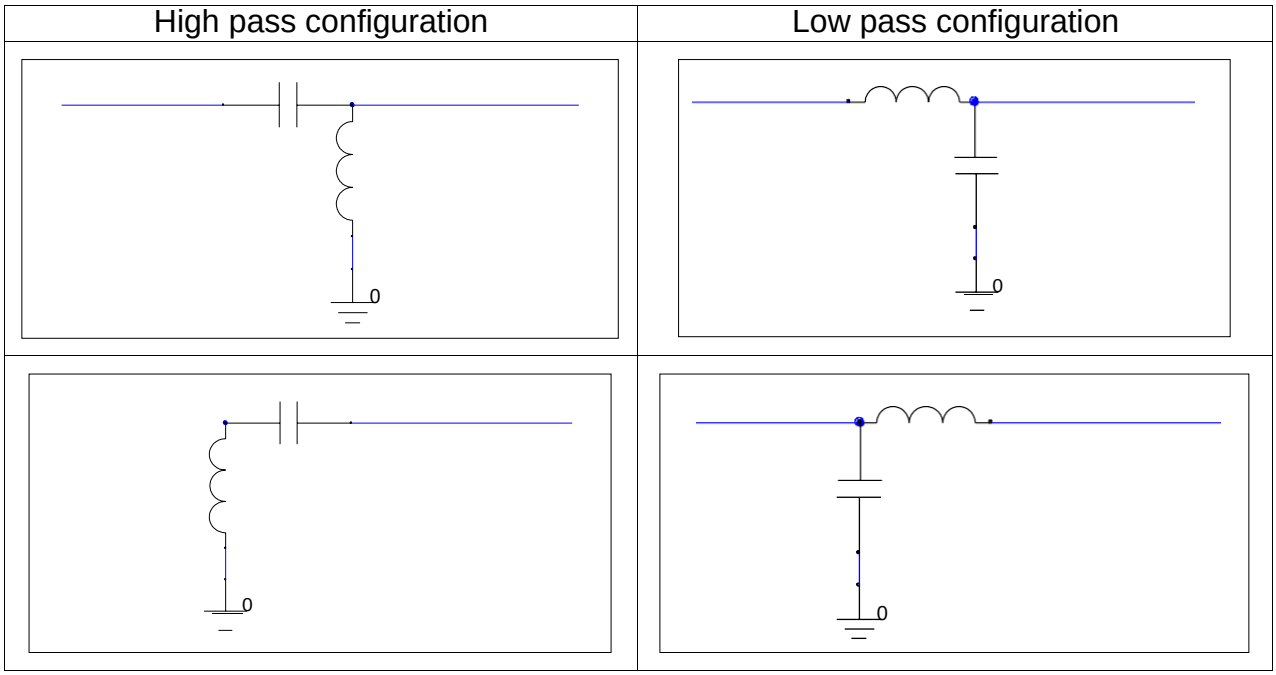


Figure 6: High pass and low pass configurations

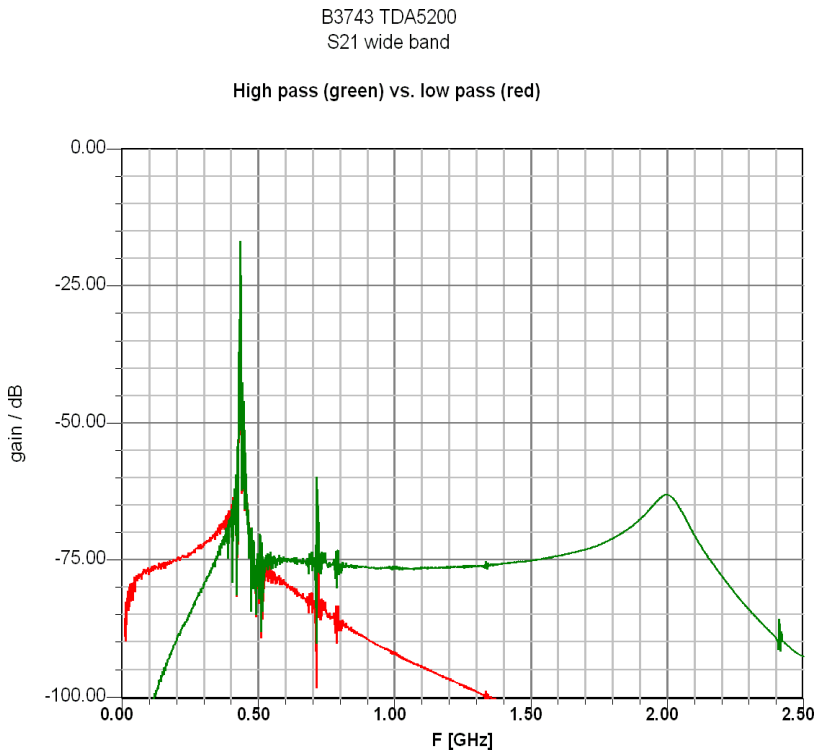


Figure 7: S_{21} response for high pass (green) vs. low pass (red) matching configurations

The use of two inductors attenuates low and high frequencies. This configuration has a band pass characteristic (Figure 8).

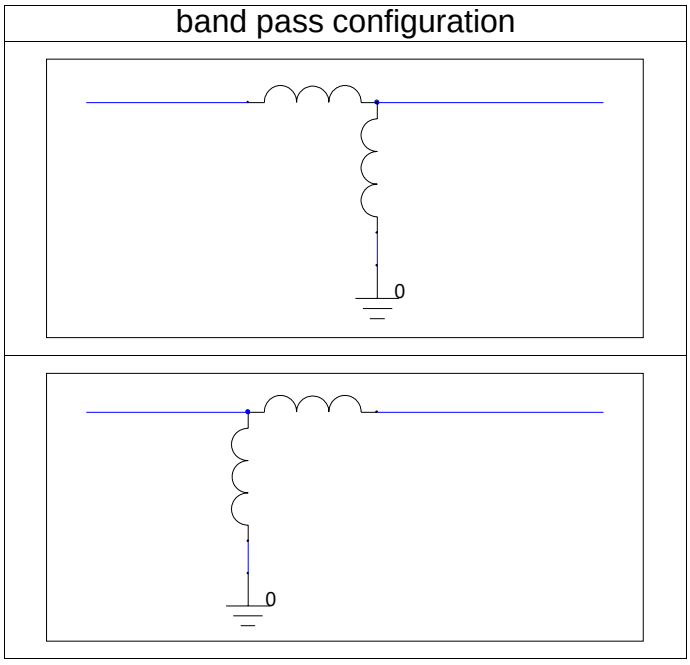


Figure 8: Band pass configurations

As the impedances of a narrow-band SAW filter and the LNA input of the Rx IC are rather capacitive than inductive, configurations with two capacitors are not possible.

The arrangement of two inductors often leads to the lowest insertion loss. Which configuration provides best stability depends on the tolerances of the components and on the transformation path in the Smith Chart.

Best results will be obtained if traces are kept short between the SAW filter and adjacent components, and if inductors with high quality factors are used. For the specification of the SAW filter the quality factors of the inductors, which are used for the matching, are usually stated in the data sheet.

The SAW filter provides an additional feature:
Even if the LNA does not include a DC block capacitor, the SAW filter will block the DC current (see Figure 9). In the static model, EPCOS SAW filters are described by capacitors, which are connected in serial or in parallel. That is the reason why there is no direct connection to ground for DC currents.

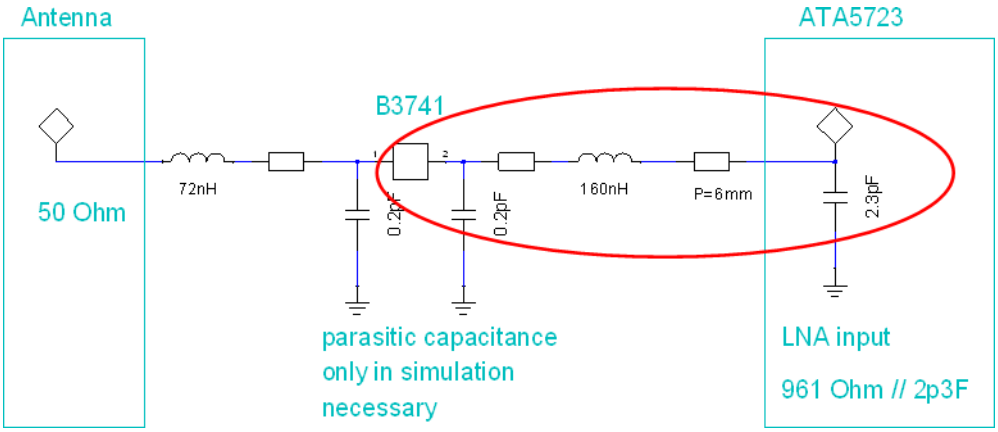


Figure 9: SAW filters fulfil DC block function

The data sheet includes maximum values of the applicable DC Voltage.

As the SAW filter is an ESD sensitive element, there might be the need of ESD protection. In the data sheet examples of ESD protection matching networks are given.

Optimization of the matching networks

The aim of all power matching approaches is a flat pass-band and a low insertion attenuation. The S_{11} in the Smith Chart indicates if the matching is already optimized.

If the pass-band region is not near to the centre of the Smith Chart, the input matching has to be optimized (Figure 10):

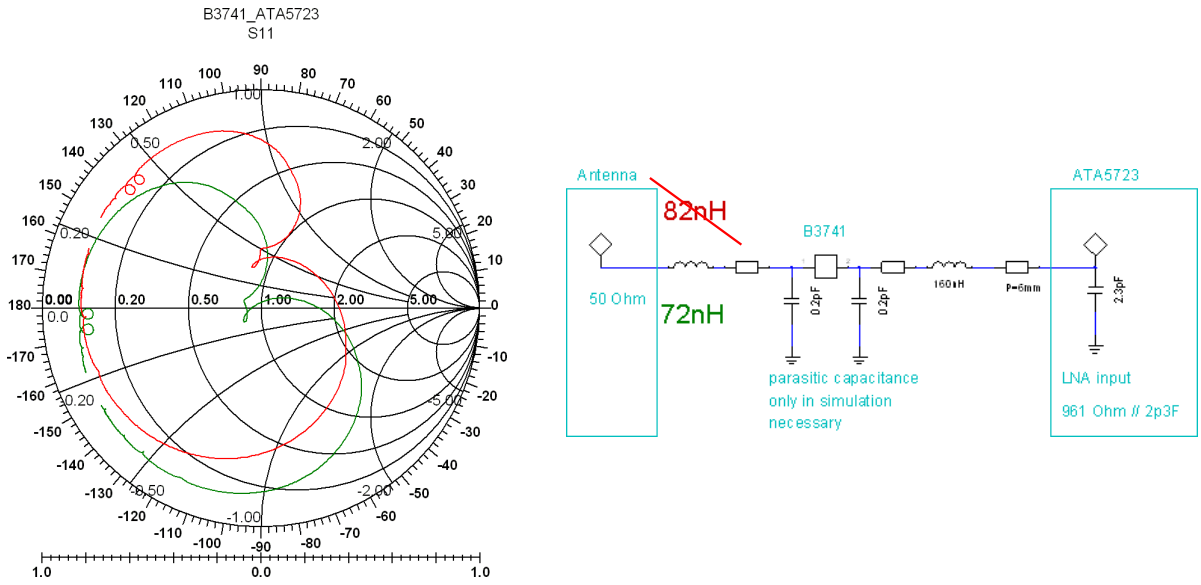


Figure 10: Optimization of the input matching

If the curve in the pass-band is “curled”, than the output matching has to be improved (Figure 11):

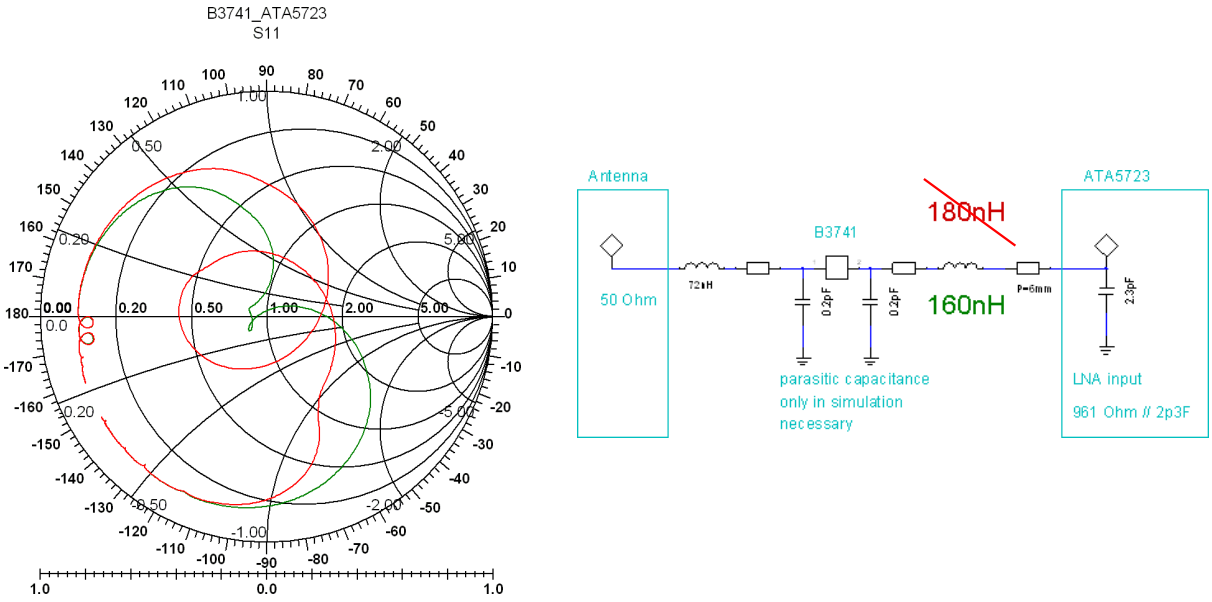


Figure 11: Optimization of the output matching

The green curve, “curled” and centred in the middle of the Smith Chart, shows an optimized matching.

Simulation of the matching of EPCOS SAW filters to integrated RKE receivers

Simulations of the matching networks for INFINEON's TDA 520x series and ATMEL's ATA 572x series are presented. On a PCB component values can change slightly because of the parasitics and the accuracy of the device models in simulations.

For the simulation inductors with quality factors of ~45 for 315MHz, ~50 for 434MHz and ~60 for 868MHz have been used. The capacitors' quality factors are higher than 100.

Furthermore micro strip lines (0.5mm common line width, 2mm length) have been integrated in the simulations for the connection of the components.

SAW Filters
B3741: narrow-band filter, quartz, 315MHz
B3743: narrow-band filter, quartz, 433.92MHz
B3744: narrow-band filter, quartz, 868.3MHz
Please look at the datasheets and at the important notes in the datasheets.

The LNA input impedances are taken from the data sheets of the receivers.
IC ATMEL
315MHz: ATA5723, 26.97 – j158.7 · R//C: 961 // 2p3
433MHz: ATA5724, 19.30 – j113.3 · R//C: 684 // 3p2
868MHz: ATA5728, 14.15 – j73.53 · R//C: 396 // 2p4

IC INFINEON
315MHz: TDA5201, 0.895 / -25.5° · R//C: 859 // 2p3
433MHz: TDA5200, 0.873 / -34.7° · R//C: 672 // 2p3
868MHz: TDA5200, 0.738 / -73.5° · R//C: 216 // 2p6

The shown matching topologies are chosen to present the variety of the matching networks. It is not guaranteed that the best topology with respect to number of components, return loss or sensitivity of the components has been taken.

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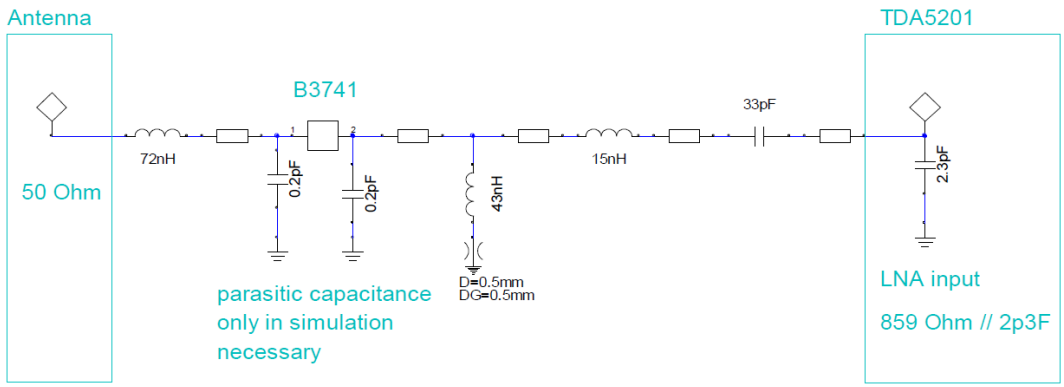
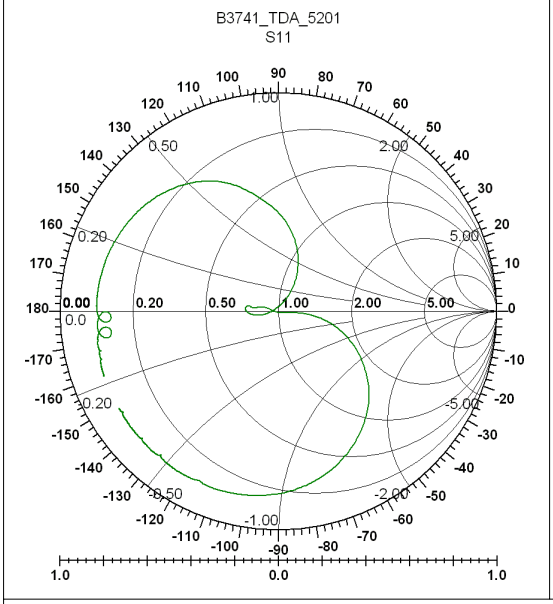
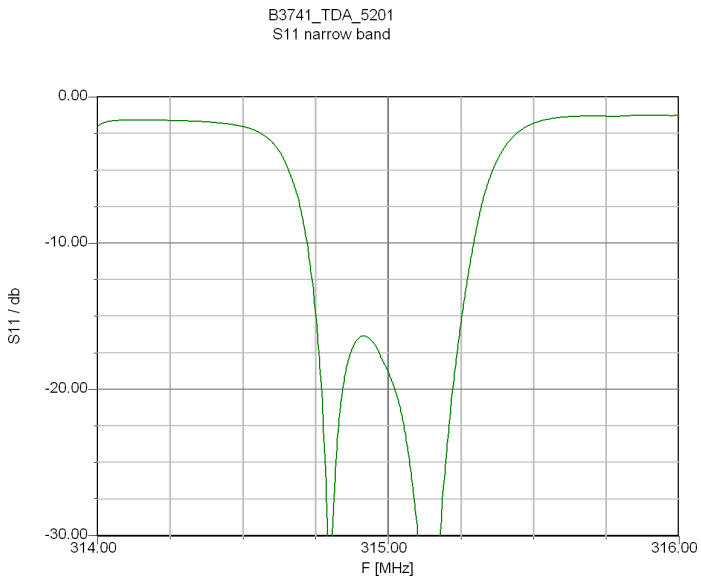
B3741 – TDA5201



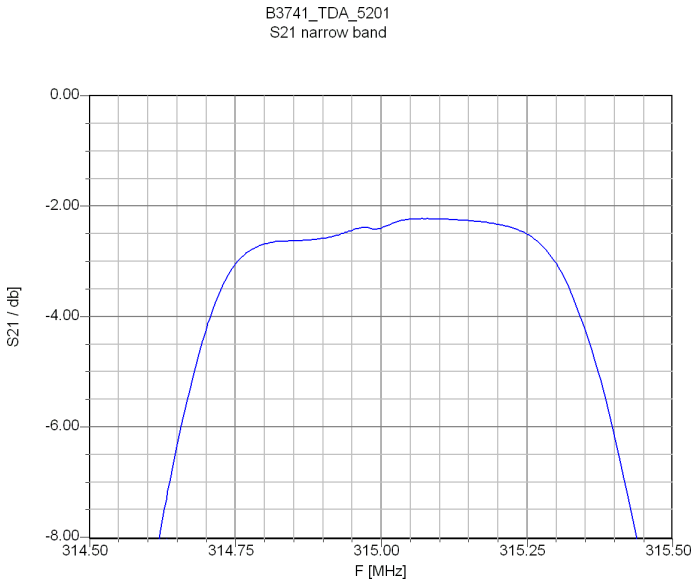
Smith Chart of S11



Return Loss of S11



Transmission narrow band



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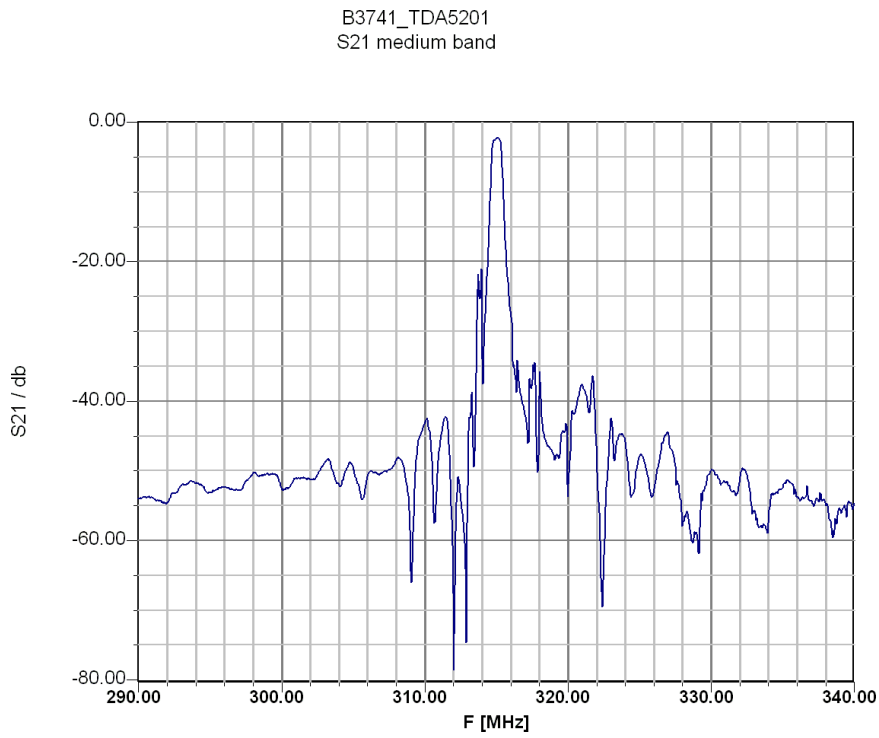
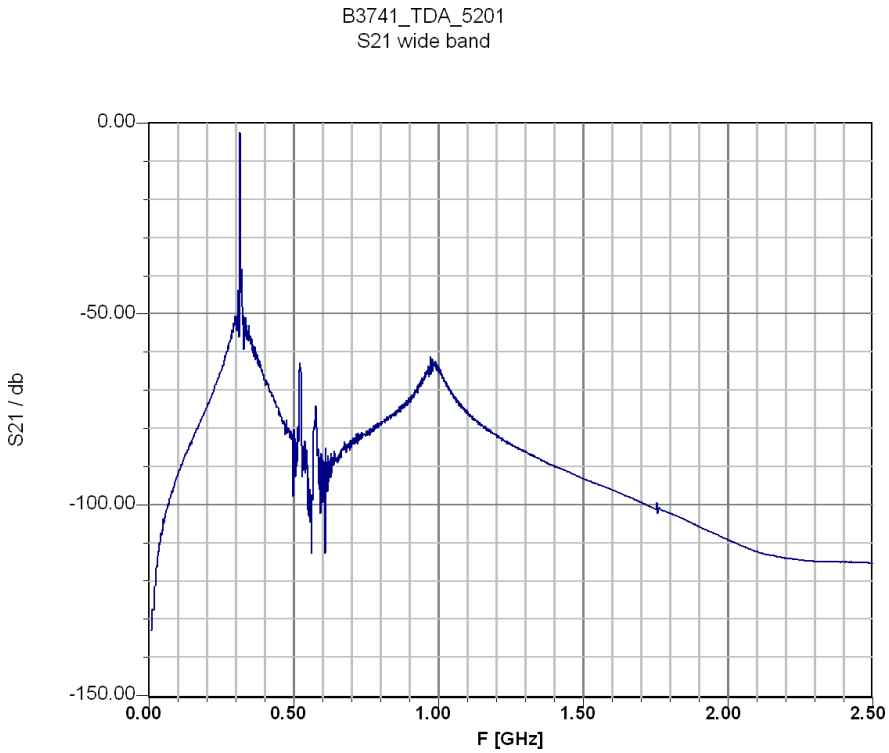
B3741 – TDA5201

Transmission medium band



Transmission wide band



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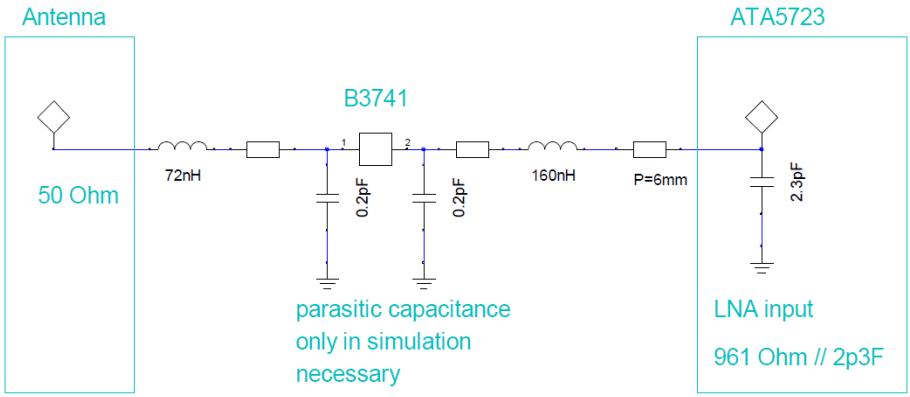
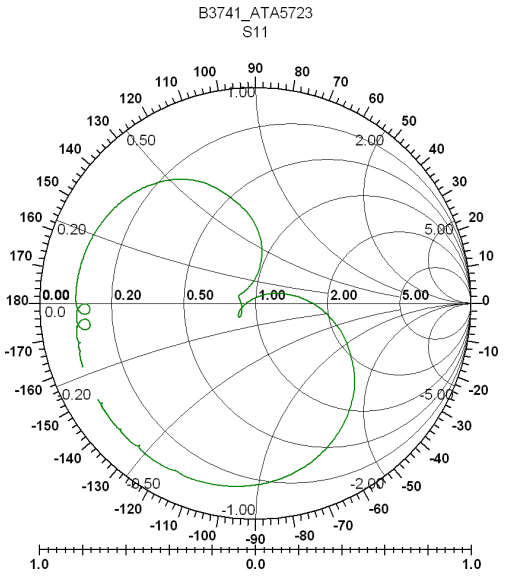
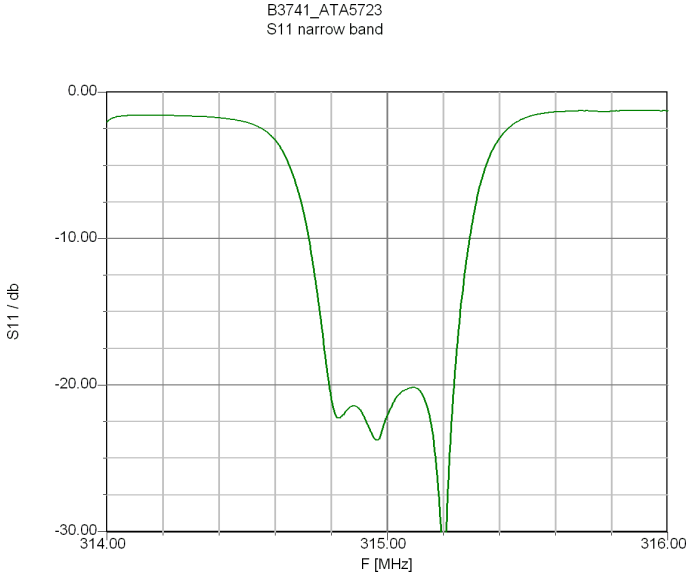
B3741 – ATA5723 - micro strip line before LNA has a physical length P = 6mm



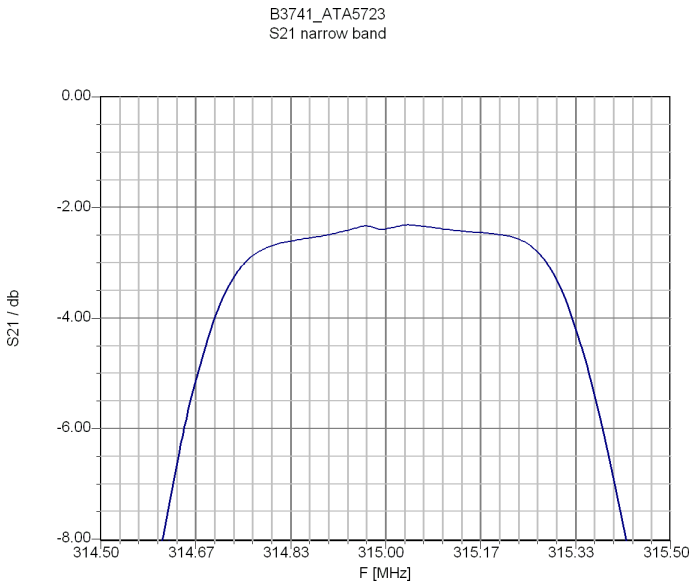
Smith Chart of S11



Return Loss of S11



Transmission narrow band



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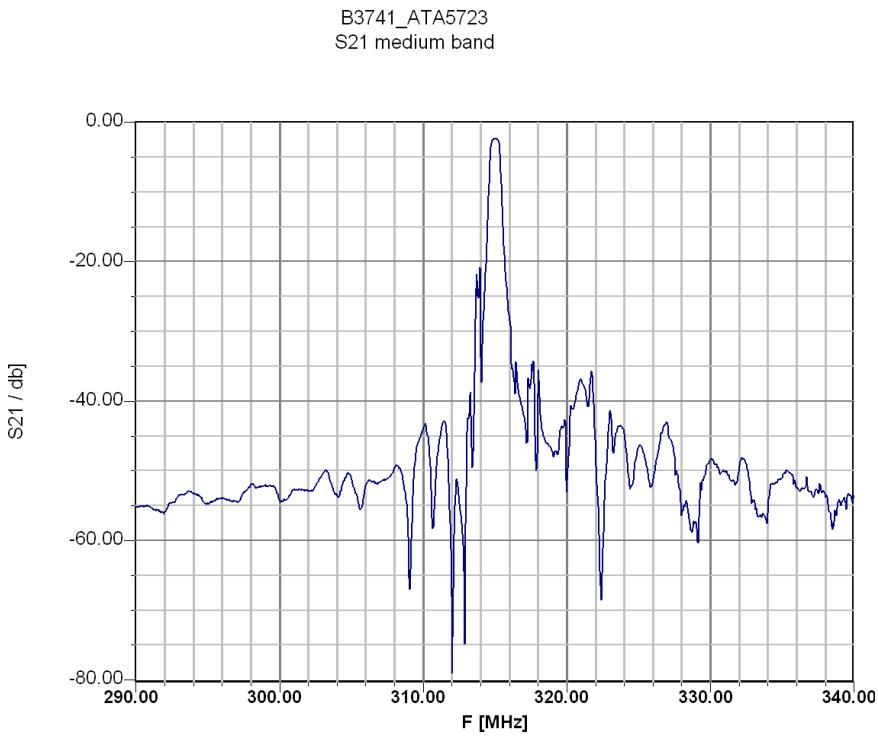
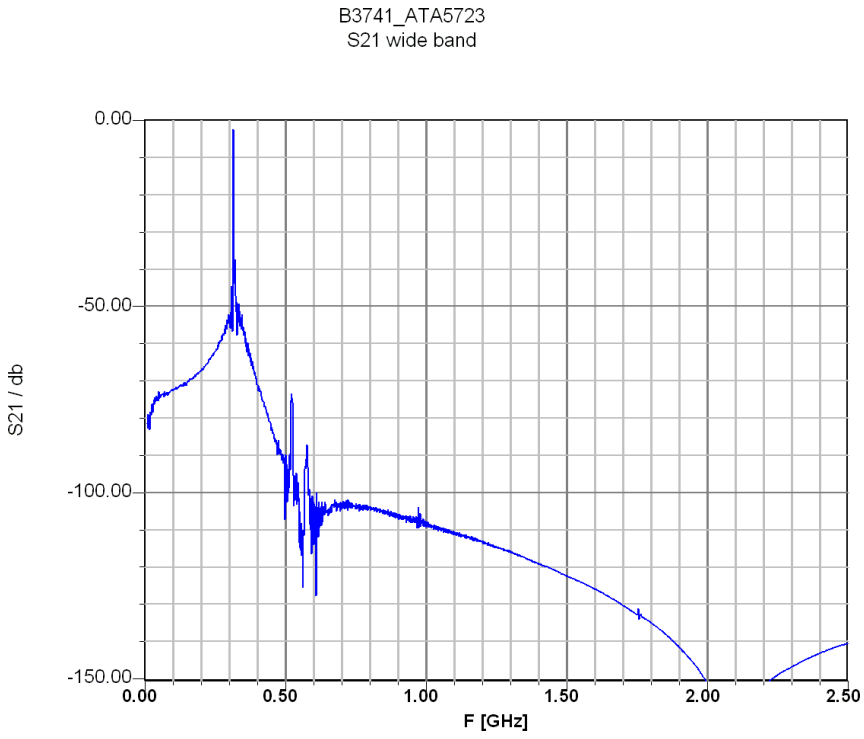
B3741 – ATA5723

Transmission medium band



Transmission wide band



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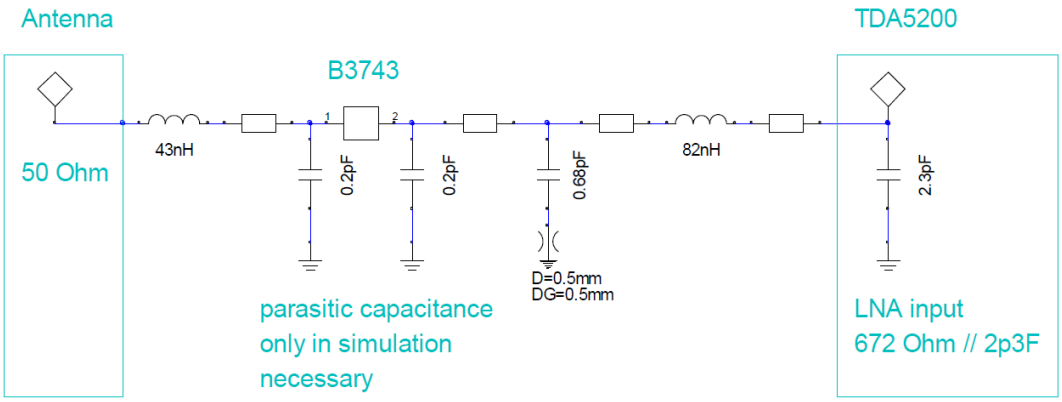
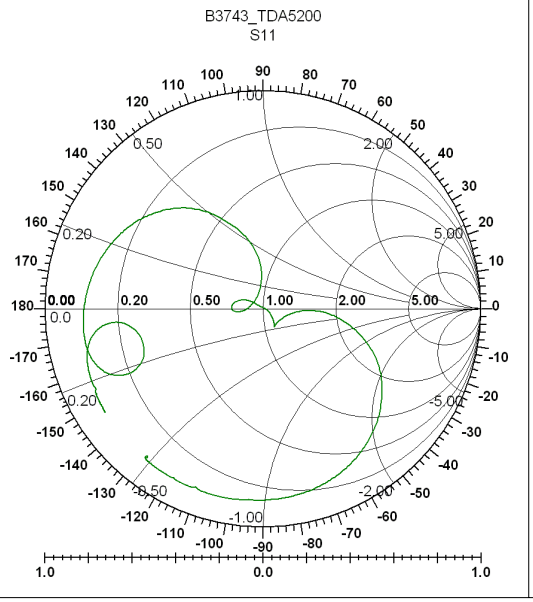
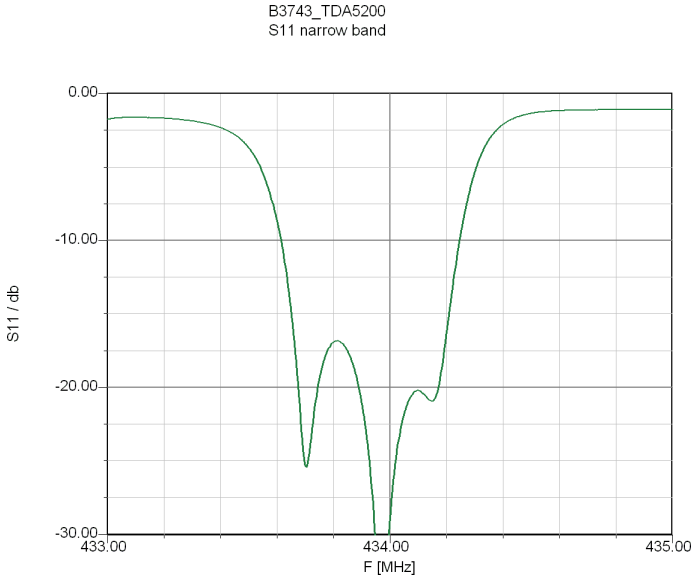
B3743 – TDA5200



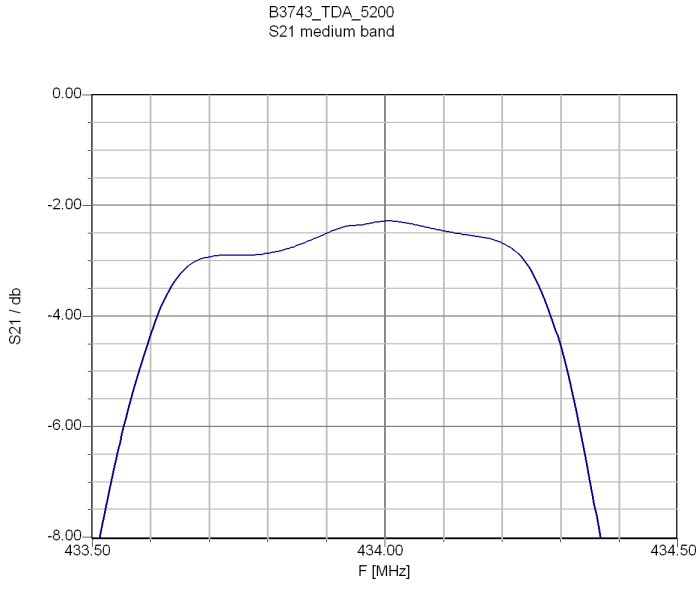
Smith Chart of S11



Return Loss of S11



Transmission narrow band



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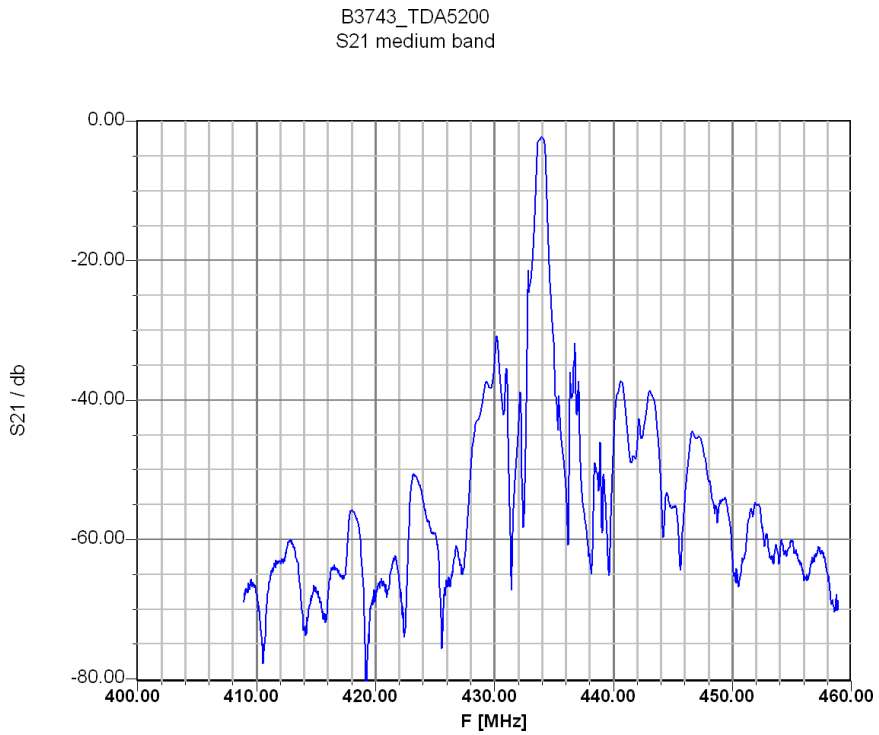
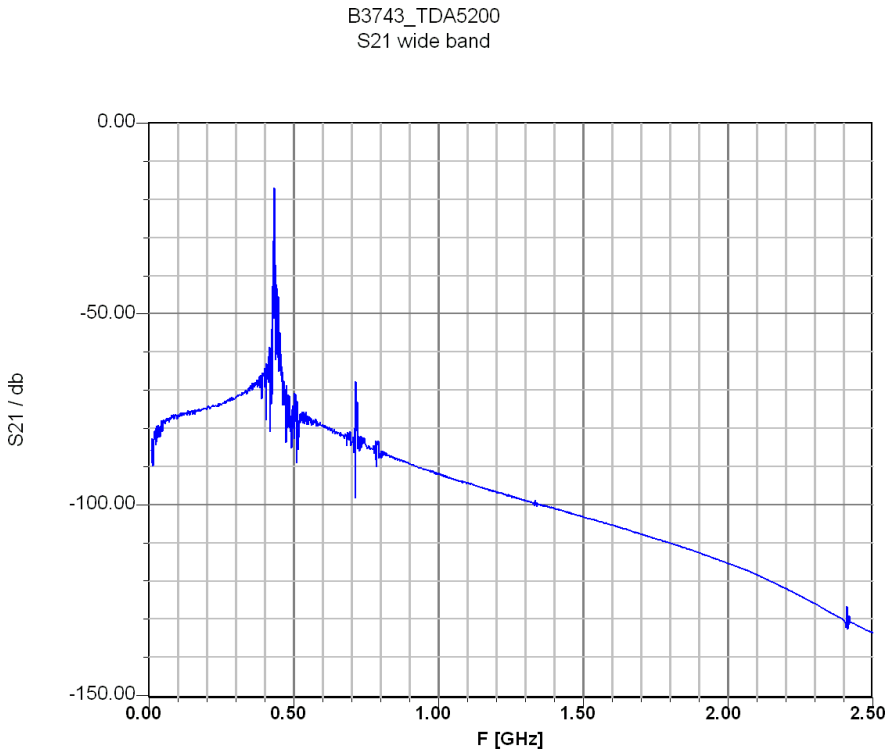
Transmission medium band



Transmission wide band



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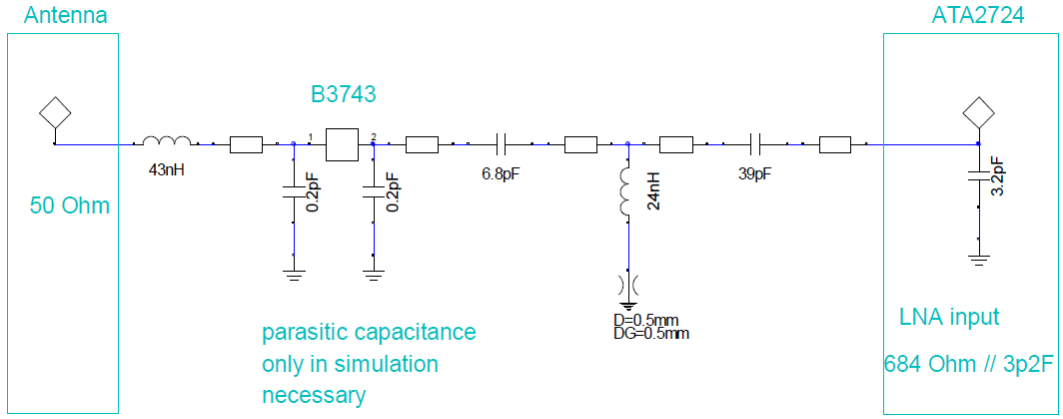
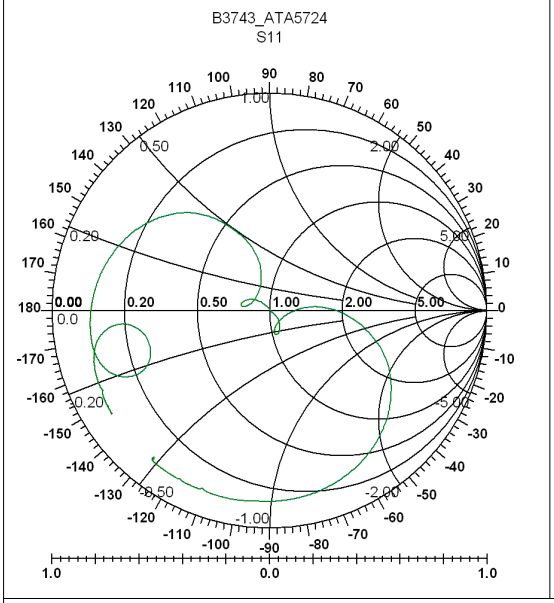
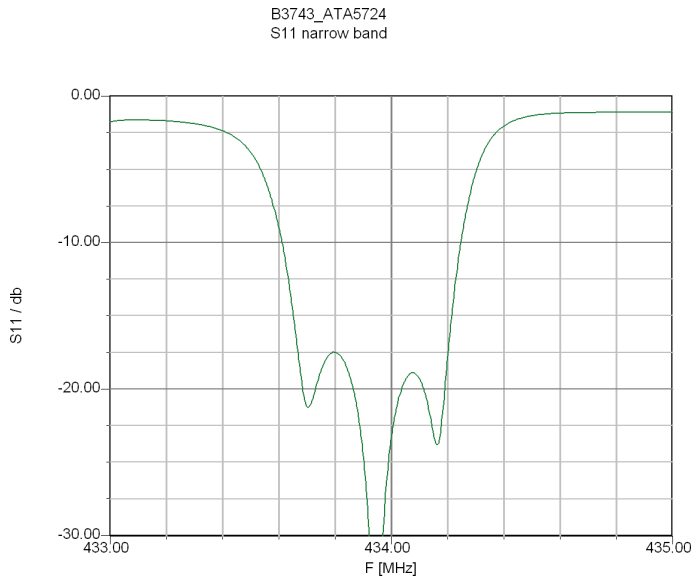


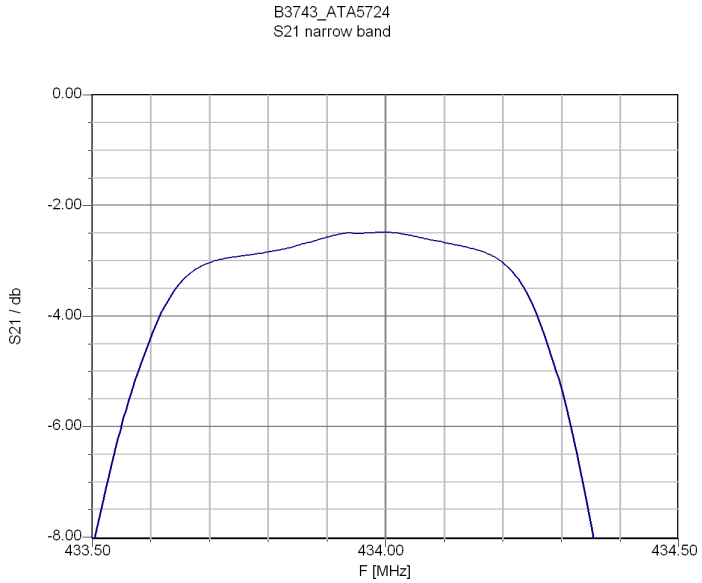
Smith Chart of S11



Return Loss of S11



Transmission narrow band



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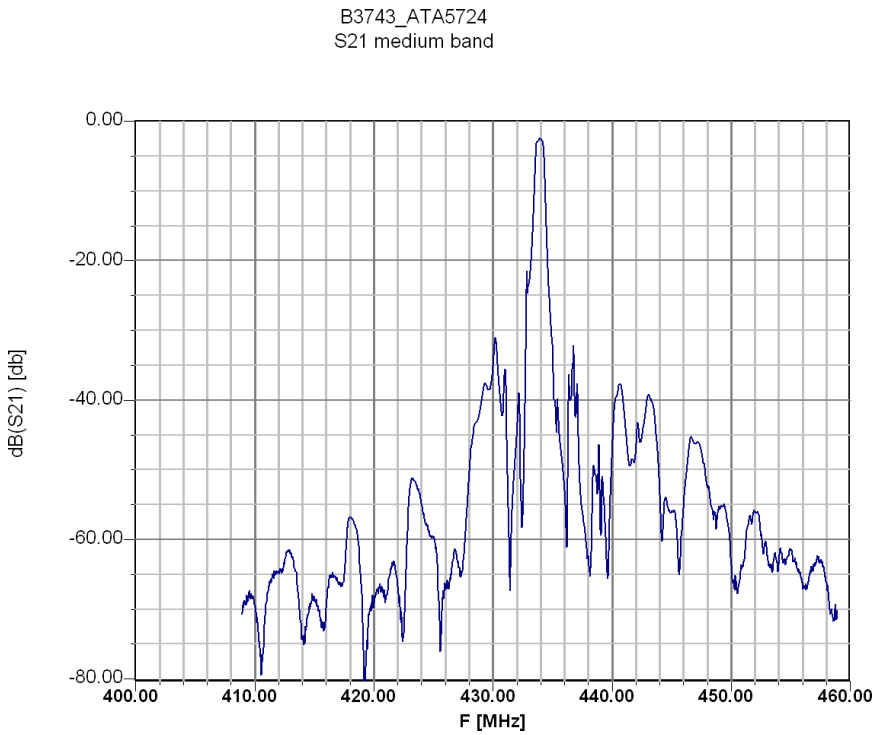
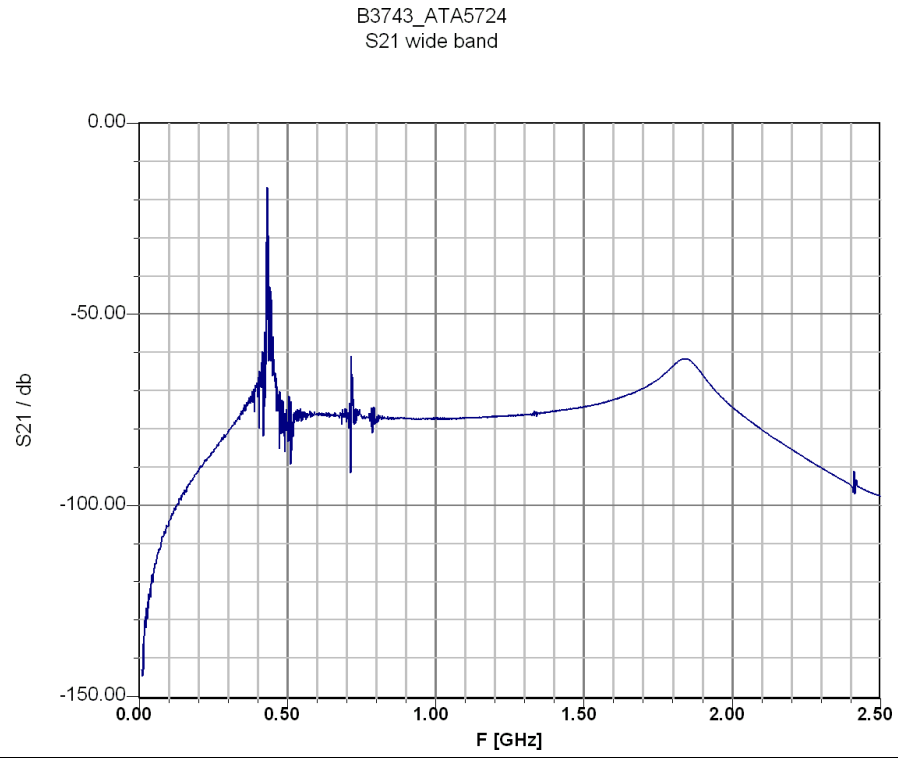
Transmission medium band



Transmission wide band



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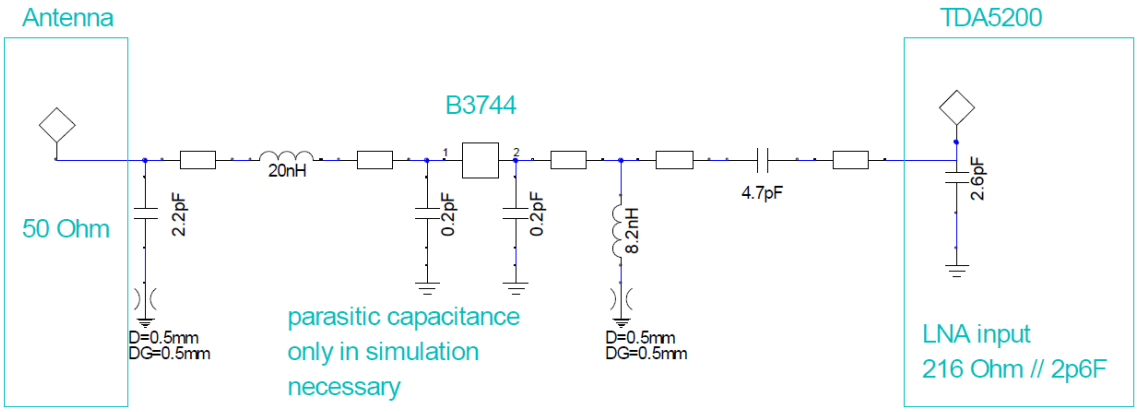
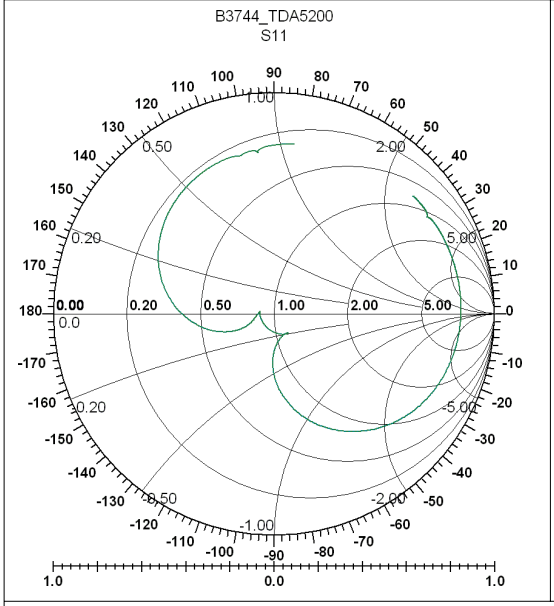
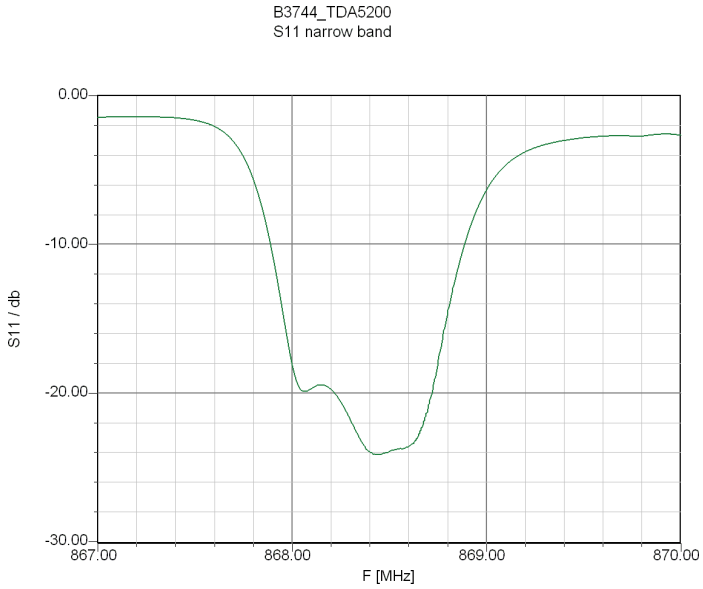


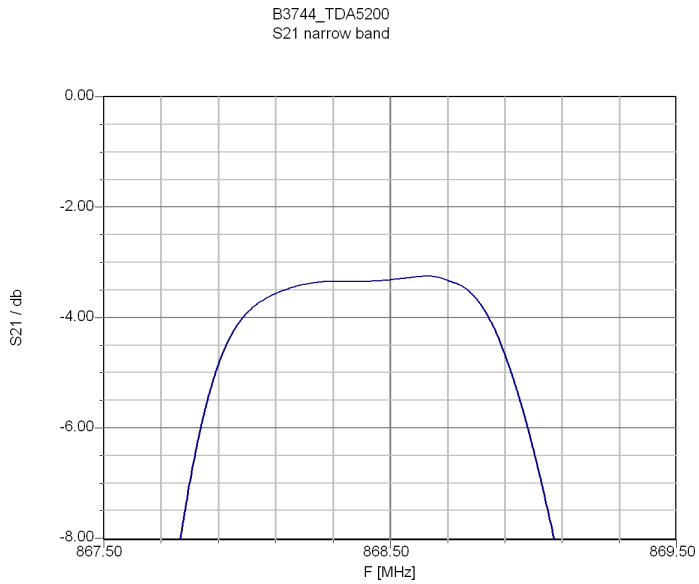
Smith Chart of S11



Return Loss of S11



Transmission narrow band



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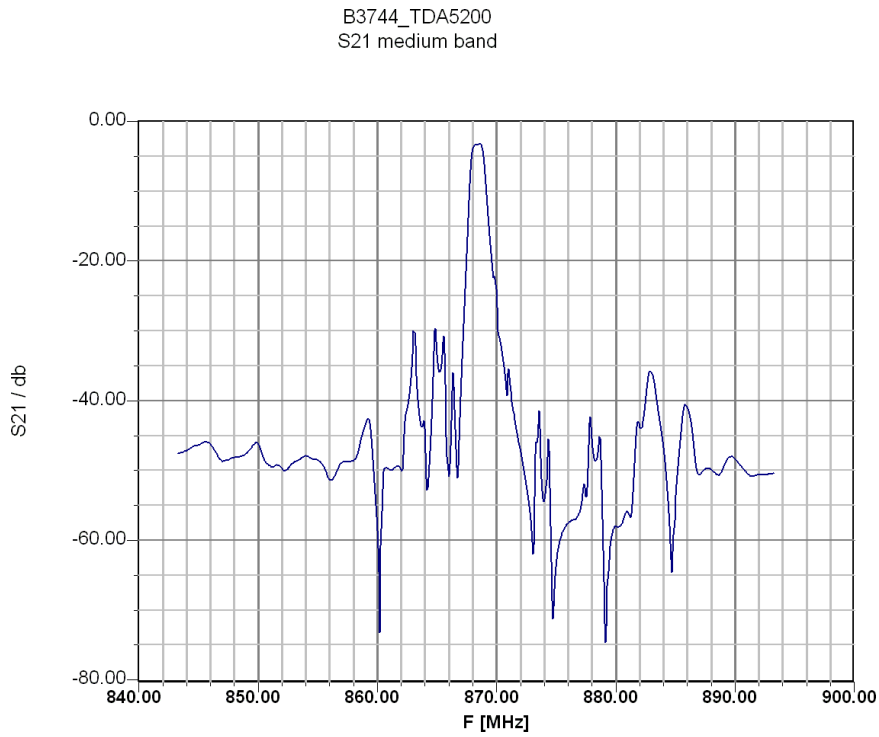
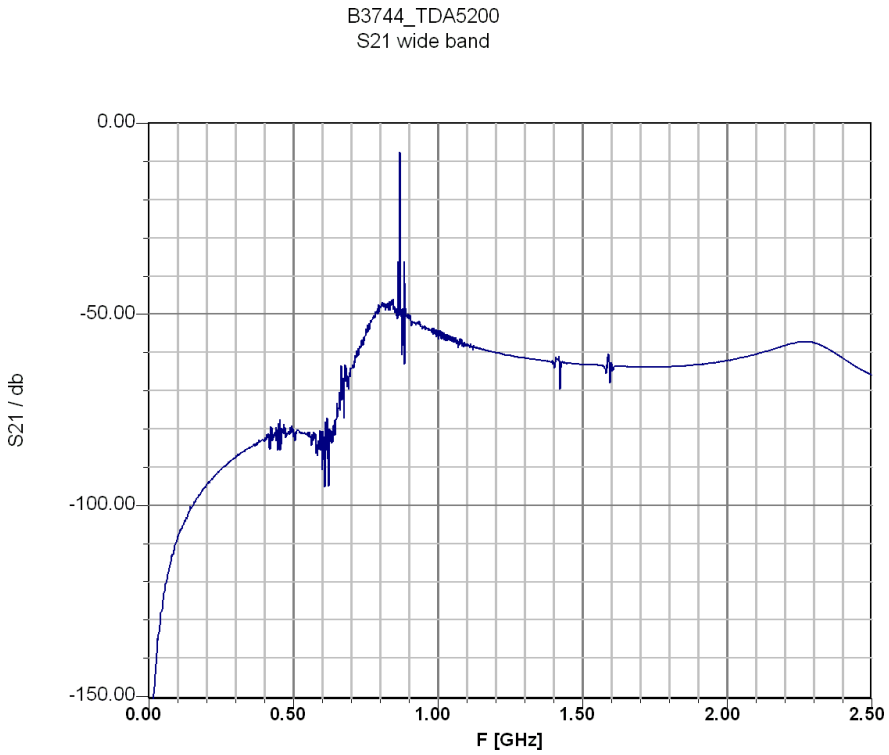
Transmission medium band



Transmission wide band



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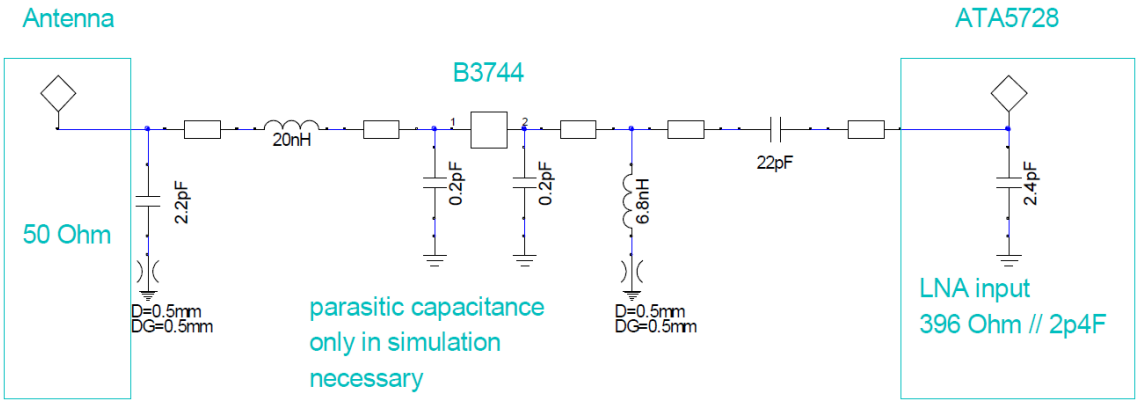
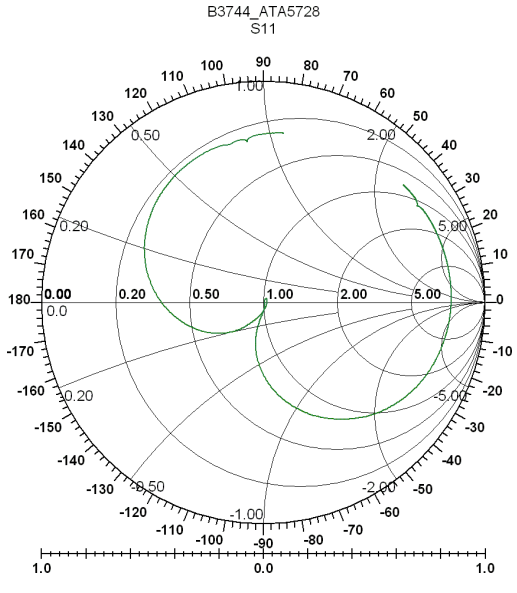
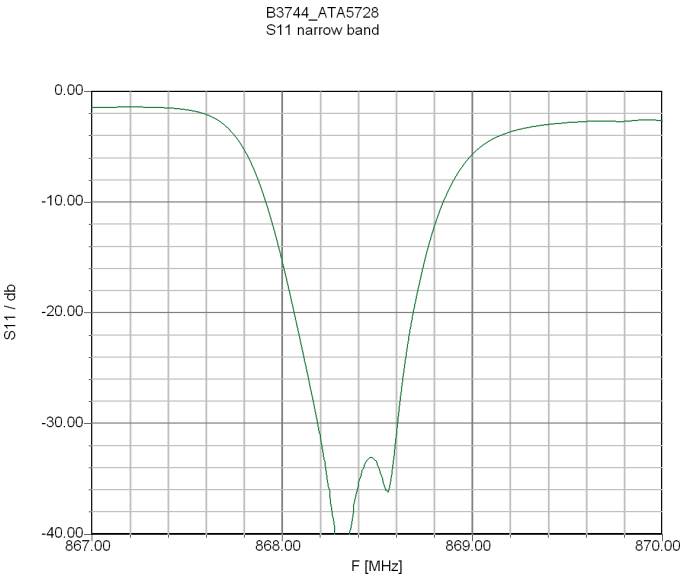


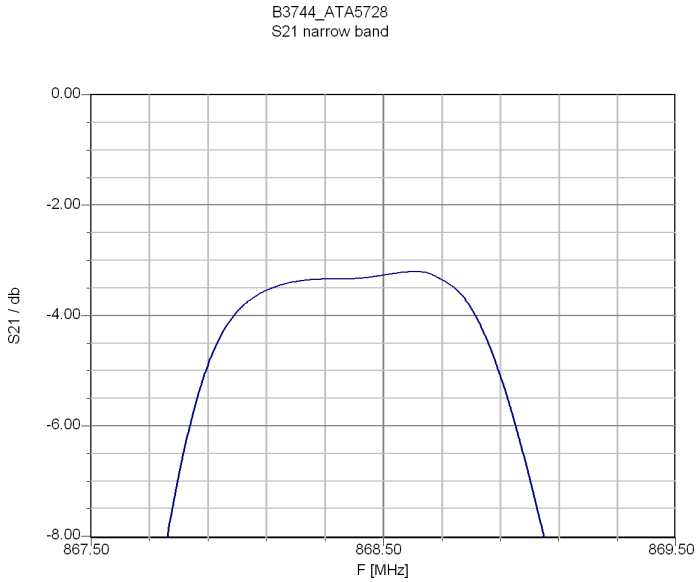
Smith Chart of S11



Return Loss of S11



Transmission narrow band



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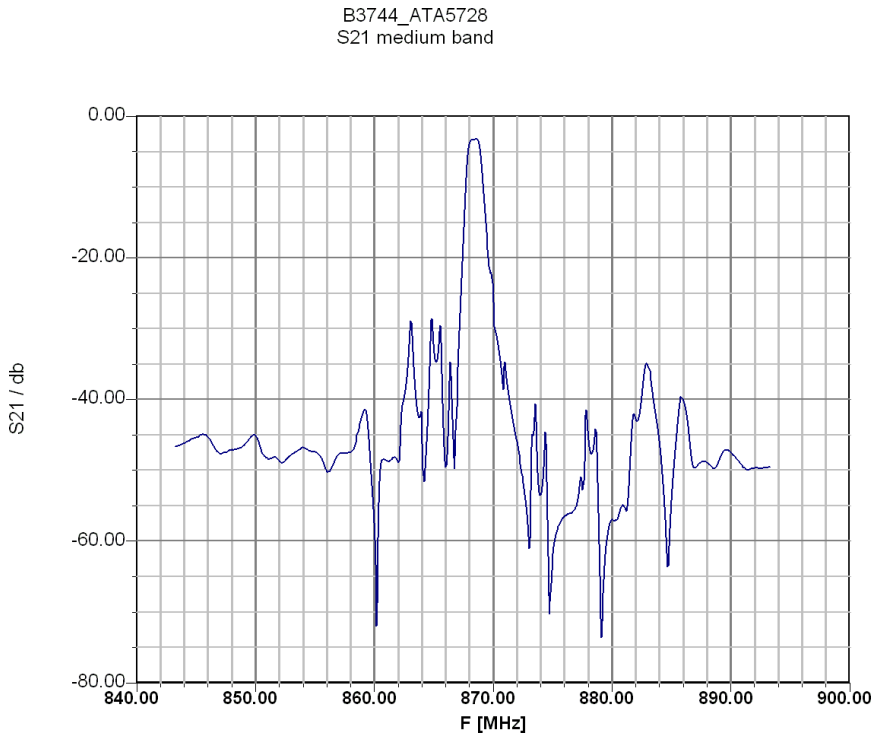
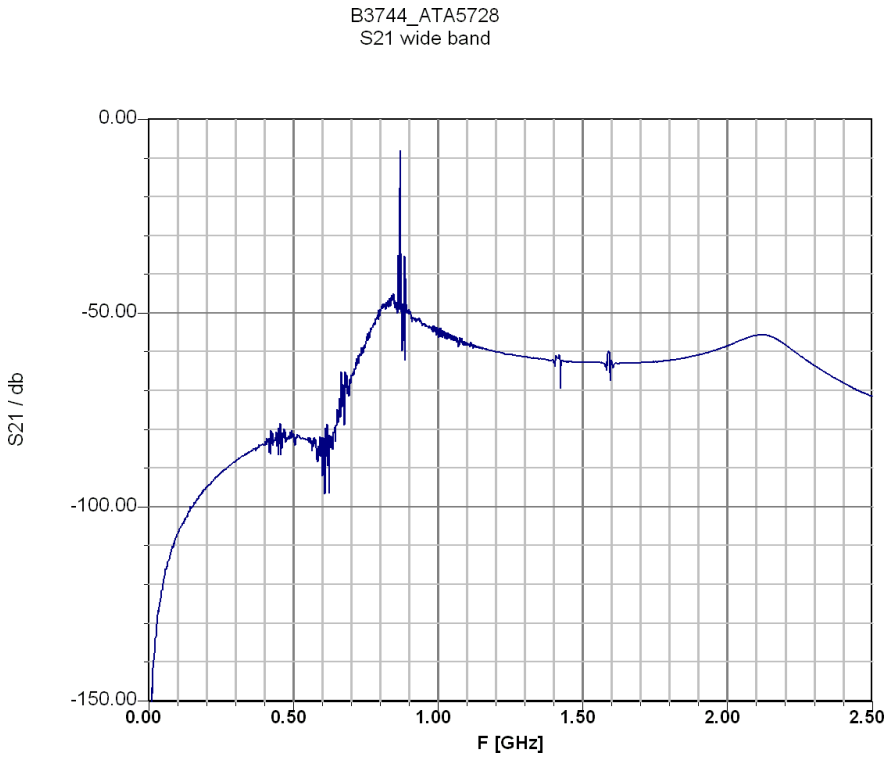
Transmission medium band



Transmission wide band