Siemens Matsushita Components

Application Note

Calculation of Matching Networks for SAW Filters

Abstract:

This application note demonstrates the use of impedance values both of filter and chip sets in the calculation of all matching networks possible. Starting out with a practical example, attention is being drawn to specific design items, such as customizing coil values with parallel capacitors and transformation of unbalanced matching networks to balanced ones.

Horst Germann
S+M OFW E MF
February 23, 1999
Munich, Germany
Reg.-No.: MFAPP05A

1. Introduction

SAW filters need a specific impedance termination for optimum performance. Some types need a power match and some others a defined power mismatch. To help the engineer calculate the optimum termination, every SAW filter datasheet from S+M states the “terminating source impedance” and the “terminating load impedance”. In the power matched case, these are the conjugate complex impedances (mean values over the passband) of the SAW filter ports.

8 various matching topologies exist for matching circuits with two elements (e.g. port 1: source or load, port 2: SAW filter input or output):

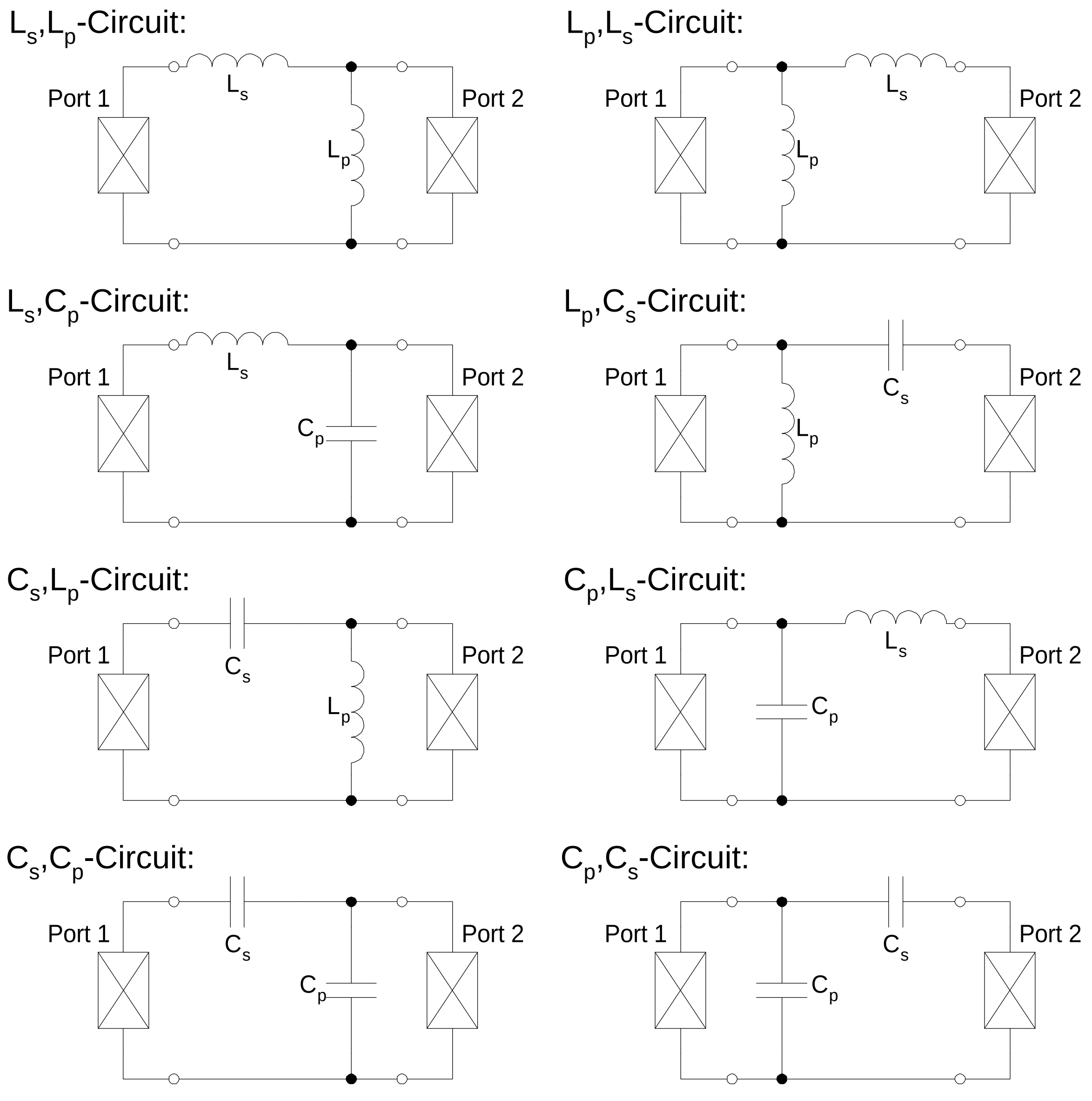


Figure 1: Possible Matching Topologies for Matching with 2 Elements

Depending on the impedance values of the ports, two or four of the matching topologies can be used to achieve the desired impedance transformation. Assuming infinite quality factors of the matching elements, there are closed formulas for calculating all possible matching networks.

2. Calculating 2-element matching networks

Step 1: Calculation of real and imaginary parts of the terminating admittances

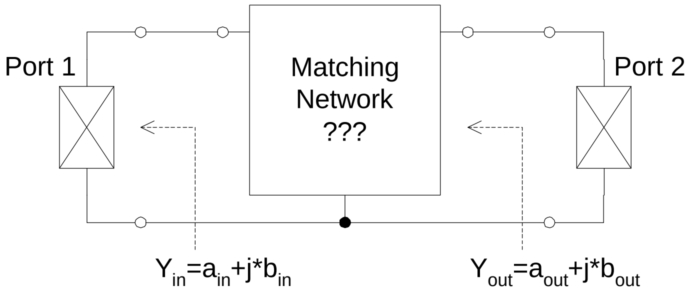


Figure 2: Definition of Terminating Admittances

In most data sheets, the source and load or the terminating impedances are stated in the parallel equivalent circuit (resistor parallel to (negative) capacitor / inductor). If there is a series circuit stated for a mixer or IF amplifier, this value has to be transformed into the equivalent parallel circuit first.

Numerical examples:

Center frequency f_0=210 MHz ⇒ $\omega_0=2\pi*f_0=1{,}32*10^9\ s^{-1}$
Real part of source: R=1000 Ω ⇒ real part of source admittance:
$a_{in}=1/R=0{,}001$ S
Imaginary part of source: C=2 pF ⇒ imaginary part of source admittance:
$b_{in}=\omega_0*C=0{,}00264$ S
Imaginary part of termination: L=40 nH ⇒ imaginary part of termination admittance:
$b_{out}=1/(-\omega_0*L)=-0{,}0189$ S (negative, because imaginary unit j put in the numerator)
or: imaginary part of termination: C=-1,44 pF ⇒ imaginary part of termination admittance:
$b_{out}=\omega_0*C=-0{,}0189$ S

Step 2: Search for possible series-parallel matching networks (left circuits in figure 1)

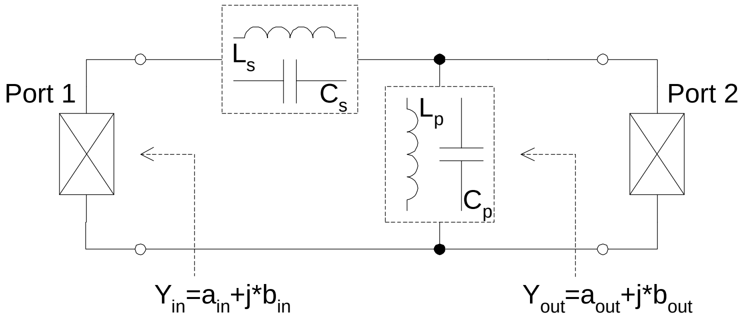


Figure 4: Possible Series-Parallel Matching Networks

Network analysis of the circuit in addition with the matching conditions lead to quadratic equations. The matching elements can be calculated from the roots of these equations. If the determinant D_{sp} is positive, there are solutions for the matching elements with real elements. If not, no series-parallel network is possible:

$$\boxed{D_{sp}=a_{in}\cdot a_{out}\,(a_{in}^2-a_{in}\cdot a_{out}+b_{in}^2)} \qquad (1)$$

Assuming $D_{sp}>0$, there are 2 pairs of solutions (if $D_{sp}=0$, both lead to the same matching elements):

$$\boxed{X_{s+}=\frac{a_{out}\cdot b_{in}+\sqrt{D_{sp}}}{a_{out}\,(a_{in}^2+b_{in}^2)}\quad\text{and}\quad B_{p+}=+\frac{\sqrt{D_{sp}}}{a_{in}}+b_{out}} \qquad (2)$$

$$X_{s-} = \frac{a_{out} \cdot b_{in} - \sqrt{D_{sp}}}{a_{out}(a_{in}^2 + b_{in}^2)} \quad \text{and} \quad B_{p-} = -\frac{\sqrt{D_{sp}}}{a_{in}} + b_{out} \tag{3}$$

Using either solution (2) or (3), the 2 pairs of matching elements can be calculated at a certain angular frequency $\omega_0 = 2\pi * f_0$, as follows:

$$\begin{aligned} X_s > 0 &\Rightarrow L_s = \frac{X_s}{w_0} \\ X_s < 0 &\Rightarrow C_s = -\frac{1}{w_0 \cdot X_s} \end{aligned} \qquad \begin{aligned} B_p > 0 &\Rightarrow C_p = \frac{B_p}{w_0} \\ B_p < 0 &\Rightarrow L_p = -\frac{1}{w_0 \cdot B_p} \end{aligned} \tag{4, 5}$$

Step 3: Search for possible parallel-series matching networks (right circuits in figure 1)

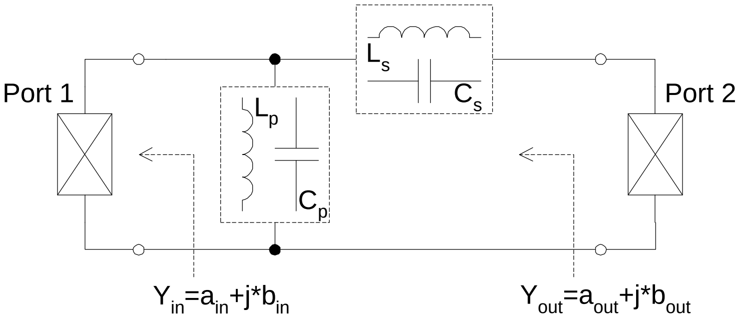


Figure 5: Possible Parallel-Series Matching Networks

Analogous to step 2, there are quadratic equations for this configuration. If the determinant D_{ps} is positive, matching networks with real elements exist. If not, no parallel-series network is possible:

$$D_{ps} = a_{in} \cdot a_{out}(a_{out}^2 - a_{in} \cdot a_{out} + b_{out}^2) \tag{6}$$

Assuming $D_{ps}>0$, there are again 2 pairs of solutions (if $D_{ps}=0$, both lead to the same matching elements):

$$B_{p+} = +\frac{\sqrt{D_{ps}}}{a_{out}} - b_{in} \quad \text{and} \quad X_{s+} = \frac{-a_{in} \cdot b_{out} + \sqrt{D_{ps}}}{a_{in}(a_{out}^2 + b_{out}^2)} \tag{7}$$

$$B_{p-} = -\frac{\sqrt{D_{ps}}}{a_{out}} - b_{in} \quad \text{and} \quad X_{s-} = \frac{-a_{in} \cdot b_{out} - \sqrt{D_{ps}}}{a_{in}(a_{out}^2 + b_{out}^2)} \tag{8}$$

Using either solution (7) or (8), the 2 pairs of matching elements can be calculated at a certain angular frequency $\omega_0 = 2\pi * f_0$, as follows:

$$\begin{aligned} B_p > 0 &\Rightarrow C_p = \frac{B_p}{w_0} \\ B_p < 0 &\Rightarrow L_p = -\frac{1}{w_0 \cdot B_p} \end{aligned} \qquad \begin{aligned} X_s > 0 &\Rightarrow L_s = \frac{X_s}{w_0} \\ X_s < 0 &\Rightarrow C_s = -\frac{1}{w_0 \cdot X_s} \end{aligned} \tag{9, 10}$$

3. Numerical example

From the S+M datasheet B4907 (IF filter for CDMA systems (f_0=210,38 MHz)), we read the following terminating impedances:

terminating source impedance: Z_S= 600 Ω || 39 nH
terminating load impedance: Z_L= 470 Ω || 33 nH

Now we calculate all possible matching networks to a source (mixer) of 50 Ω and a load (IF amplifier) with an impedance of 1000 Ω || 0,8 pF.

Calculation of the input matching network:

We begin with the calculation of real and imaginary parts of the admittances, as defined in figure (2):

$\omega_0=2\pi^*f_0=2\pi^*210{,}38\ \text{MHz}=1{,}322^*10^9\ \text{s}^{-1}$
$Y_{in}=a_{in}+j^*b_{in}$ ⇒ $a_{in}=1/(50\ \Omega)=0{,}02$ S
$b_{in}=0$ (no imaginary part)
$Y_{out}=a_{out}+j^*b_{out}$ ⇒ $a_{out}=1/(600\ \Omega)=0{,}00167$ S
$b_{out}=1/(-\omega_0{}^*L)=1/(-1{,}322^*10^9\ \text{s}^{-1}\ ^*\ 39\ \text{nH})=-0{,}0194$ S

Now we calculate the determinant D_{sp} for the series-parallel network according to formula (1):

$$D_{sp}=a_{in}\cdot a_{out}(a_{in}^2-a_{in}\cdot a_{out}+b_{in}^2)=1{,}2244\cdot 10^{-8}\ \text{S}^4$$

$D_{sp}>0$, therefore solutions for series-parallel circuits exist according to formula (2) and (3):

$$X_{s+}=\frac{a_{out}\cdot b_{in}+\sqrt{D_{sp}}}{a_{out}(a_{in}^2+b_{in}^2)}=165{,}7\,\Omega>0\Rightarrow L_{s+}=\frac{X_{s+}}{w_0}=125\,\text{nH}\quad\text{and}$$

$$B_{p+}=+\frac{\sqrt{D_{sp}}}{a_{in}}+b_{out}=-0{,}0139\,\text{S}<0\Rightarrow L_{p+}=-\frac{1}{w_0\cdot B_{p+}}=55\,\text{nH}$$

or

$$X_{s-}=\frac{a_{out}\cdot b_{in}-\sqrt{D_{sp}}}{a_{out}(a_{in}^2+b_{in}^2)}=-165{,}7\,\Omega<0\Rightarrow C_{s-}=-\frac{1}{w_0\cdot X_{s-}}=4{,}6\,\text{pF}\quad\text{and}$$

$$B_{p-}=-\frac{\sqrt{D_{sp}}}{a_{in}}+b_{out}=-0{,}0249\,\text{S}<0\Rightarrow L_{p-}=-\frac{1}{w_0\cdot B_{p-}}=30\text{nH}$$

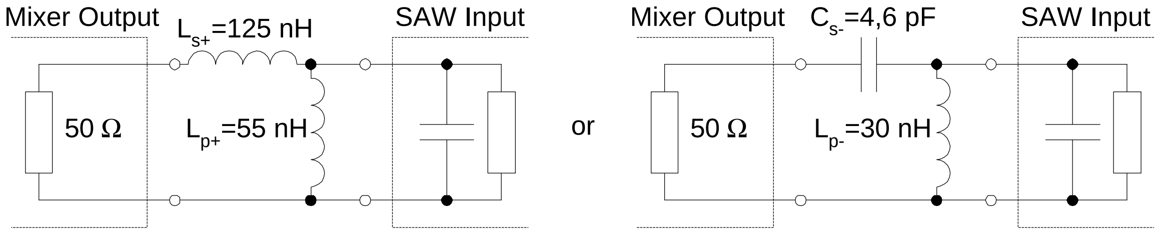


Figure 6: Possible Series-Parallel Matching Networks for Input Matching of B4907

Now we calculate the determinant D_{ps} for the parallel-series network according to formula (6):

$$D_{ps} = a_{in} \cdot a_{out}(a_{out}^2 - a_{in} \cdot a_{out} + b_{out}^2) = 1{,}1548 \cdot 10^{-8}\,\mathrm{S}^4$$

$D_{ps}>0$, therefore solutions for parallel-series circuits also exist according to formula (7) and (8):

$$B_{p+} = +\frac{\sqrt{D_{ps}}}{a_{out}} - b_{in} = 0{,}0643\,\mathrm{S} > 0 \Rightarrow C_{p+} = \frac{\mathrm{B}_{p+}}{w_0} = 49\,\mathrm{pF} \quad \text{and}$$

$$X_{s+} = \frac{-a_{in} \cdot b_{out} + \sqrt{D_{ps}}}{a_{in}(a_{out}^2 + b_{out}^2)} = 65{,}8\,\Omega > 0 \Rightarrow L_{s+} = \frac{X_{s+}}{w_0} = 50\,\mathrm{nH}$$

or

$$B_{p-} = -\frac{\sqrt{D_{ps}}}{a_{out}} - b_{in} = -0{,}0643\,\mathrm{S} < 0 \Rightarrow L_{p-} = -\frac{1}{w_0 \cdot B_{p-}} = 12\,\mathrm{nH} \qquad \text{and}$$

$$X_{s-} = \frac{-a_{in} \cdot b_{out} - \sqrt{D_{ps}}}{a_{in}(a_{out}^2 + b_{out}^2)} = 36{,}6\,\Omega > 0 \Rightarrow L_{s-} = \frac{X_{s-}}{w_0} = 28\,\mathrm{nH}$$

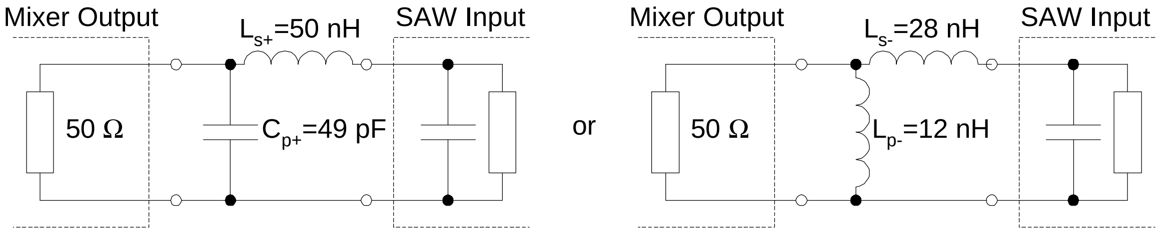


Figure 7: Possible Parallel-Series Matching Networks for Input Matching of B4907

Now we have found 4 possible matching circuits just for the input of the filter. **Which one should we choose?** In most cases, L-L matching circuits are more stable against tolerances of matching elements, but a coil, especially a high-Q coil, is more expensive than a capacitor. So, for most applications one of the C-L circuits will be chosen. In our example, 2 possibilities remain, the series-C parallel-L circuit of figure (6) and the parallel-C series-L circuit of figure (7). The series-C parallel-L circuit of figure (6) implies a DC-decoupling, which is being realized in most cases.

Calculation of the output matching network:

Again we calculate the real and imaginary parts of the admittances as defined in figure (2). $\underline{Y_{in}}$ is now the <u>load</u> impedance of the IF amplifier and $\underline{Y_{out}}$ the <u>terminating load</u> impedance of the SAW filter:

$\omega_0=2\pi * f_0=2\pi * 210{,}38$ MHz$=1{,}322 * 10^9$ s^{-1}
$Y_{in}=a_{in}+j * b_{in}$ ⇒ $a_{in}=1/(1000\ \Omega)=0{,}001$ S
$b_{in}=\omega_0 * C=1{,}322 * 10^9$ s^{-1} * 0,8 pF=0,00106 S
$Y_{out}=a_{out}+j * b_{out}$ ⇒ $a_{out}=1/(470\ \Omega)=0{,}00213$ S
$b_{out}=1/(-\omega_0 * L)=1/(-1{,}322 * 10^9$ s^{-1} * 33 nH)=-0,0229 S

We calculate the determinant D_{sp} for the series-parallel network according formula (1):

$$D_{sp} = a_{in} \cdot a_{out}(a_{in}^2 - a_{in} \cdot a_{out} + b_{in}^2) = -1{,}3632 \cdot 10^{-14}\ \mathrm{S}^4$$

$D_{sp}<0$, therefore solutions for series-parallel circuits do not exist.

Now we have to search for parallel-series matching circuits according formula (6):

$$D_{ps} = a_{in} \cdot a_{out} (a_{out}^2 - a_{in} \cdot a_{out} + b_{out}^2) = 1{,}1221 \cdot 10^{-9}\,\mathrm{S}^4$$

$D_{ps}>0$, therefore solutions for parallel-series circuits exist according formula (7) and (8):

$$B_{p+} = +\frac{\sqrt{D_{ps}}}{a_{out}} - b_{in} = 0{,}0147\,\mathrm{S} > 0 \Rightarrow C_{p+} = \frac{\mathrm{B}_{p+}}{w_0} = 11\,\mathrm{pF} \quad \text{and}$$

$$X_{s+} = \frac{-a_{in} \cdot b_{out} + \sqrt{D_{ps}}}{a_{in}(a_{out}^2 + b_{out}^2)} = 106{,}6\,\Omega > 0 \Rightarrow L_{s+} = \frac{X_{s+}}{w_0} = 81\,\mathrm{nH}$$

or

$$B_{p-} = -\frac{\sqrt{D_{ps}}}{a_{out}} - b_{in} = -0{,}0168\,\mathrm{S} < 0 \Rightarrow L_{p-} = -\frac{1}{w_0 \cdot B_{p-}} = 45\,\mathrm{nH} \quad \text{and}$$

$$X_{s-} = \frac{-a_{in} \cdot b_{out} - \sqrt{D_{ps}}}{a_{in}(a_{out}^2 + b_{out}^2)} = -20{,}0\,\Omega < 0 \Rightarrow C_{s-} = -\frac{1}{w_0 \cdot X_{s-}} = 38\,\mathrm{pF}$$

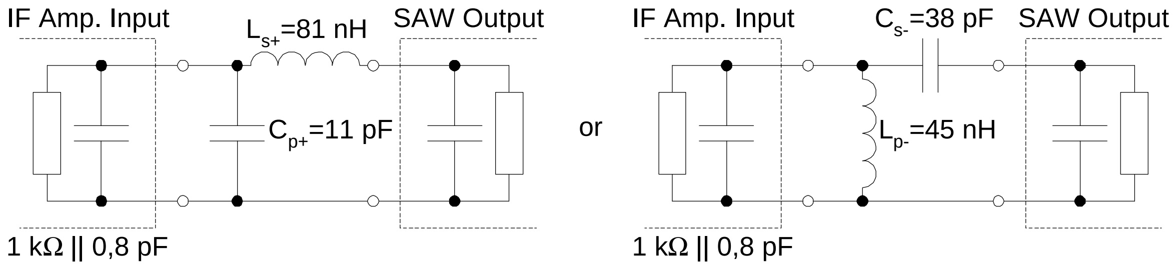


Figure 8: Possible Parallel-Series Matching Networks for Output Matching of B4907

Again we have the possibility to chose between 2 C-L matching circuits. In most cases the L_{p-}-C_{s-} matching (right side of figure (8)) is chosen, not only for implying a DC-decoupling but also for being more cost effective if the series element is split for balanced operation. We will see in chapter 4.3. how to transform single ended matching networks to balanced matching networks.

4. Hints for practical use

All calculated matching networks are only as accurate as the terminating impedances. Therefore, in many cases fine tuning on the final PCB will be necessary. But with the calculated starting values given, it is possible to start close to the optimum. In addition Siemens Matsushita can provide information and support, such as matching circuits for certain chipsets, and 2-port or 4-port scattering-parameters for simulation.

4.1. Some facts from inside the SAW filter

The terminating impedances of SAW filters are often given for single ended operation. Many IF filters from S+M can be used in both modes, single ended or fully balanced. Balanced operation avoids a so-called ground loop, the voltage drop caused by a current flow through parasitic inductors between the filter ground pins and the PCB ground. This ground loop is often the main cause of PCB feedthrough, unless the PCB is carefully designed.

For most IF filters (e.g. for GSM, AMPS and DECT), the differences of the filter capacitances for balanced and single ended mode are so small as to be negligible. In contrast IF filters for CDMA applications need a very precise matching. Therefore, let's have a closer look at the differences between the two modes:

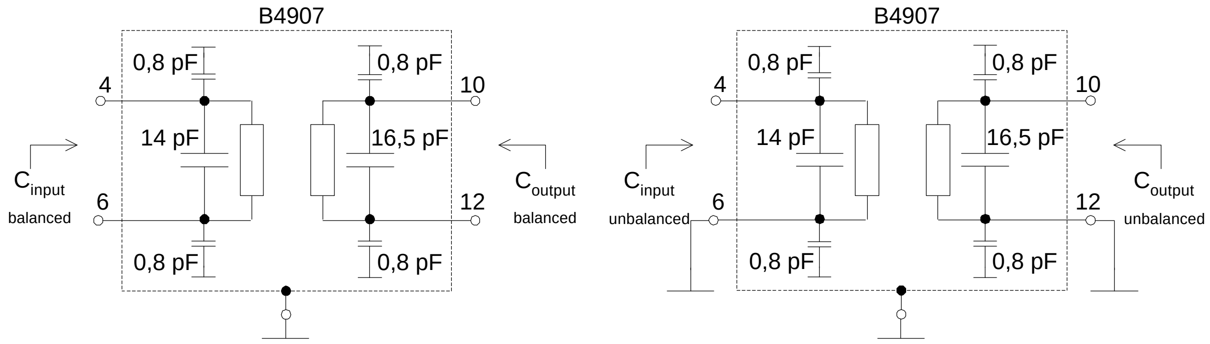


Figure 9: Detailed Equivalent Circuits for Balanced and Single Ended Driven SAW Filters

The estimated capacitance between each filter pin (including PCB pad) and ground is typically 0,8 pF. If the balanced input or output capacitances are measured, the 2 capacitors to ground act as a series circuit between the balanced ports. In the single ended case, one of the capacitors is shorted. Therefore we calculate the capacitances to be:

$C_{input,balanced}$=14 pF+0,8 pF/2=14,4 pF $C_{input,unbalanced}$=14 pF+0,8 pF=14,8 pF
$C_{output,balanced}$=16,5 pF+0,8 pF/2=16,9 pF $C_{output,unbalanced}$=16,5 pF+0,8 pF=17,3 pF

The same mechanism applies to parasitic elements on the PCB and, of course, within mixer and IF amplifier chips. As for hardware this means that the values for the parallel matching elements, which have to compensate the parasitics, can differ in the balanced case from the single ended case. Therefore S+M provides 4-port filter s-parameters for simulation, which take this effect into account.

The real parts of the filter impedances are identical for the balanced and the single ended mode.

4.2. Customizing coil values with parallel capacitors

For most applications, the available E12 standard series of RF coils is sufficient for a good matching. In some cases (e.g. CDMA IF filters), there is a need for customized coil values. Although coil manufacturers (e.g. Coilcraft) offer customized element values, at least throughout the development period of a telephone board, an easy tuning method for fixed coil values is desired.

IF SAW filters are narrow band devices, and within the filter passband a parallel circuit of a coil and a small capacitor act as an admittance, which is equivalent to a coil with a greater value.

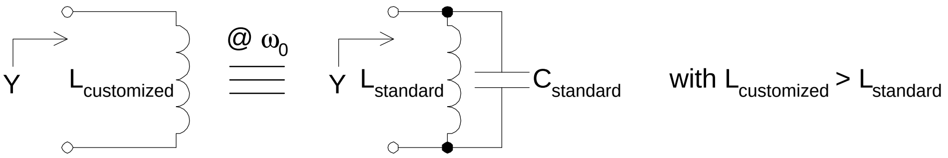


Figure 10: Equivalence of a Coil Value to a Coil Capacitor Parallel Circuit at a Certain Frequency

The admittance of the circuits shall be equal at $\omega_0 = 2\pi * f_0$:

$$\boxed{Y = \frac{1}{j \cdot w_0 \cdot L_{customized}} = \frac{1}{j \cdot w_0 \cdot L_{standard}} + j \cdot w_0 \cdot C_{standard}} \qquad (11)$$

Now, the needed parallel capacitor $C_{standard}$ can be calculated as follows:

$$\boxed{C_{standard} = \frac{L_{customized} - L_{standard}}{w_0^2 \cdot L_{customized} \cdot L_{standard}}} \qquad (12)$$

Numerical example:

We have calculated a coil value of $L_{customized}$=45 nH parallel to the IF amplifier (right side of figure (8)). The next smaller coil in the E12 series is $L_{standard}$=39 nH. At a frequency of f_0=210,38 MHz, we calculate the following parallel capacitor necessary:

$$C_{standard} = \frac{45\,\mathrm{nH} - 39\,\mathrm{nH}}{4p^2 \cdot (210{,}38\,\mathrm{MHz})^2 \cdot 45\,\mathrm{nH} \cdot 39\,\mathrm{nH}} = 1{,}96\,\mathrm{pF} \Rightarrow \text{chosen}: C_{standard} = 2\,\mathrm{pF}$$

A value of $C_{standard}$=2 pF is available in 0402 size. The capacitor value should be chosen as small as possible, and the standard coil as large as possible, because the quality factor $Q_{L,customized}$ of the coil will be degraded slightly (assuming an infinite Q of the capacitor):

$$\boxed{Q_{L,customized} = Q_{L,standard} \cdot \frac{L_{standard}}{L_{customized}}} \qquad (13)$$

For our example assuming a coil quality factor of $Q_{L,standard}$=45, this means:

$$Q_{L,customized} = 45 \cdot \frac{39\,\mathrm{nH}}{45\,\mathrm{nH}} = 39$$

For the calculation of the over-all tolerance of the customized coil let us assume that we have 2% tolerance parts with both L and C being at the upper end of the tolerance limits. The maximum coil value would be:

$$L_{custom.,max} = \frac{1}{\frac{1}{L_{stand.,max}} - w_0^2 \cdot C_{stand.,max}} = \frac{1}{\frac{1}{1{,}02 \cdot 39\,\mathrm{nH}} - 4p^2 (210{,}38\,\mathrm{MHz})^2 \cdot 1{,}02 \cdot 2\,\mathrm{pF}} = 46{,}4\,\mathrm{nH}$$

This is 2,7 % more than the exact calculated value of $L_{customized}$=45,2 nH. Therefore, the new matching element tolerance is 2,7% in the worst case. The smaller the fine tuning capacitor is, the smaller the tolerance degradation will be.

4.3. Transformation of unbalanced matching networks to balanced ones

For most applications, the terminating impedances both in the single ended and the fully balanced driven case are quite similar (except for small corrections; see chapter 4.1.). The following chart shows how to transform the matching element values:

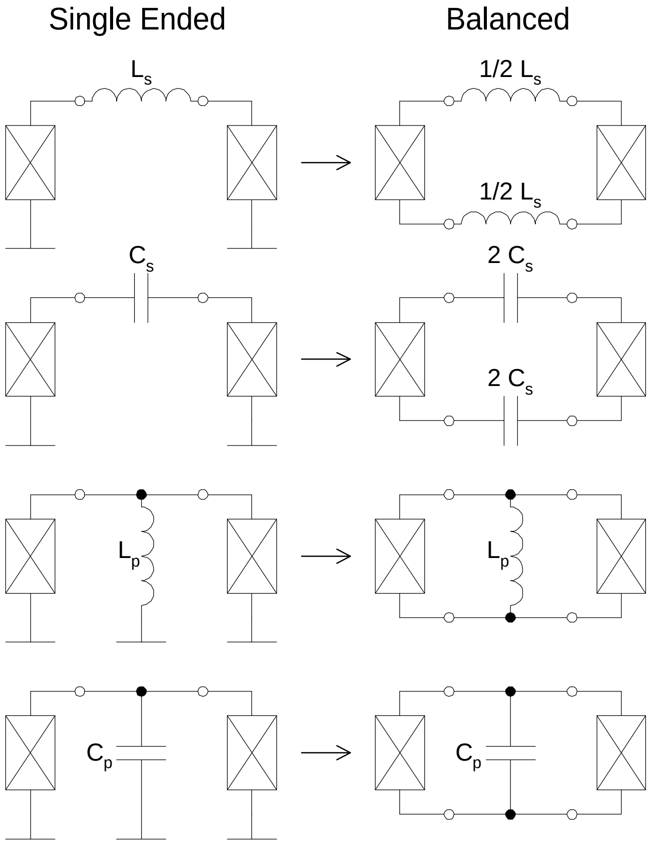


Figure 11: Equivalence of Single Ended and Balanced Matching Networks

Some balanced mixers need a bias voltage at the outputs (open collector mixers). In that case, the matching network can be used for biasing. The next picture shows the transformation of the matching network for the open collector:

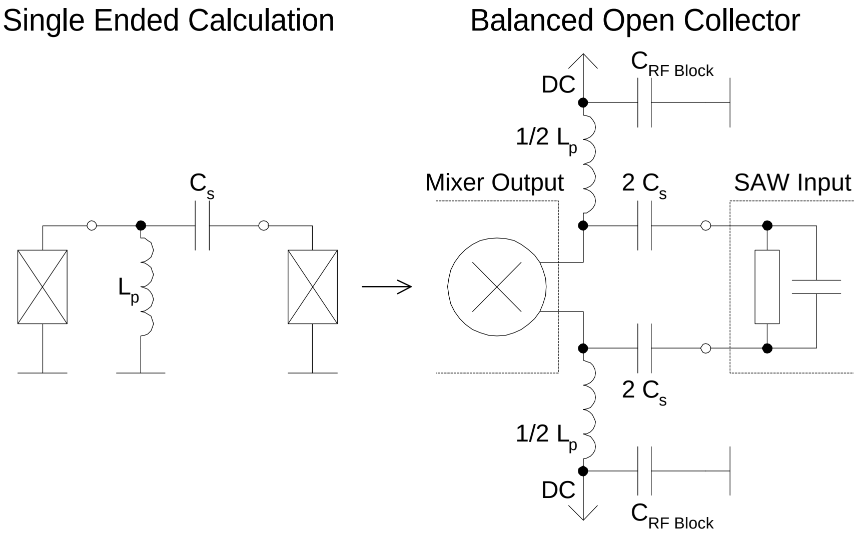


Figure 12: Transformation of Single Ended Networks for Open Collector Outputs

4.4. Using coils with non-infinite quality factors for calculation

Coils used for matching in modern mobile phones often have quality factors ranging from Q=15 to Q=45. Therefore, their parallel resistances are mostly higher than the termination impedances. But in some cases, e.g. matching to open collector mixer outputs, the parallel resistance of these coils can be lower than the termination. In this case, the quality factors of the coils must be taken into account for the calculation of the matching network.

The filter will be no longer matched to the open collector, but mainly to the parallel resistance of the two open collector biasing coils. Therefore, the impedance value, to which the filter is matched, depends on the values of the matching elements itself. To perform the calculation, we have to guess starting values for the matching elements. This will lead to a starting value for the real part of the terminating impedance.

This impedance can now be used for a more accurate calculation of the matching elements. If the element values differ widely from the starting values, the terminating impedance has to be re-checked, and the matching element values have to be calculated again. In most cases the element values are being calculated precisely enough by only a few iteration.

Numerical example:

We calculate a matching network for the S+M B8100 (IF filter for DECT systems (f_0=110,59 MHz)), to an open collector mixer. The terminating source impedances of the B8100 are stated in the datasheet: 600 Ω || 240 nH. The open collector output (including the PCB parasitics) shall have an impedance of 20 kΩ || 2,5 pF. The quality factor of the matching coils shall be Q_L=45, and the quality factor of the capacitors shall be near to infinite (Q_C>100).

We guess values of 150 nH for the open collector coils on each balanced port, which means an parallel inductor of L_p=300 nH according to figure (12). The parallel resistor can be calculated as follows:

$$R_{p,Lp} = Q_L \cdot w_0 \cdot L_p = 45 \cdot 2p \cdot 110{,}59\,\mathrm{MHz} \cdot 300\,\mathrm{nH} = 9{,}38\,\mathrm{k\Omega}$$

The real part of the source impedance R_{Source}, to which the filter is matched, is calculated as a parallel circuit of the open collector impedance and the coil parallel resistor:

$$R_{Source} = \frac{20\,\mathrm{k\Omega} \cdot 9{,}4\,\mathrm{k\Omega}}{20\,\mathrm{k\Omega} + 9{,}4\,\mathrm{k\Omega}} = 6{,}38\,\mathrm{k\Omega}$$

The real part of the source admittance is therefore: $a_{in}=1/R_{Source}=1{,}57*10^{-4}$ S

Computation of the other admittances needed for the calculation:

Center frequency f_0=110,59 MHz ⇒ $\omega_0=2\pi*f_0=6{,}95*10^8\ s^{-1}$
Imaginary part of source: C=2,5 pF ⇒ imaginary part of source admittance:
$b_{in}=\omega_0*C=0{,}00174$ S
Real part of termination: R=600 Ω ⇒ real part of termination admittance:
$a_{out}=1/R=0{,}00167$ S
Imaginary part of termination: L=240 nH ⇒ imaginary part of termination admittance:
$b_{out}=1/(-\omega_0*L)=-0{,}006$ S

We are looking for a parallel-series matching network and therefore, we calculate the determinant D_{ps} according to formula (6):

$$D_{ps} = a_{in} \cdot a_{out}\,(a_{out}^2 - a_{in} \cdot a_{out} + b_{out}^2) = 1{,}0101 \cdot 10^{-11}\,\mathrm{S}^4$$

$D_{ps}>0$, therefore solutions for parallel-series circuits exist according to formula (7) and (8):

$$B_{p+} = +\frac{\sqrt{D_{ps}}}{a_{out}} - b_{in} = 1{,}63\cdot 10^{-4}\ \mathrm{S} > 0 \Rightarrow C_{p+} = \frac{\mathrm{B_{p+}}}{w_0} = 0{,}2\ \mathrm{pF} \quad \text{and}$$

$$X_{s+} = \frac{-a_{in}\cdot b_{out} + \sqrt{D_{ps}}}{a_{in}(a_{out}^2 + b_{out}^2)} = 677\ \Omega > 0 \Rightarrow L_{s+} = \frac{X_{s+}}{w_0} = 970\ \mathrm{nH}$$

or

$$B_{p-} = -\frac{\sqrt{D_{ps}}}{a_{out}} - b_{in} = -0{,}0036\ \mathrm{S} < 0 \Rightarrow L_{p-} = -\frac{1}{w_0\cdot B_{p-}} = 395\ \mathrm{nH} \quad \text{and}$$

$$X_{s-} = \frac{-a_{in}\cdot b_{out} - \sqrt{D_{ps}}}{a_{in}(a_{out}^2 + b_{out}^2)} = -367\ \Omega < 0 \Rightarrow C_{s-} = -\frac{1}{w_0\cdot X_{s-}} = 3{,}9\ \mathrm{pF}$$

We have to choose the latter parallel-L serial-C network, because we need open collector parallel coils, anyway. The calculated value for L_{p-} differs from the estimated coil L_p=300 nH. The new parallel resistor of the open collector coils will be:

$$R_{p,Lp} = Q_L\cdot w_0\cdot L_{p-} = 45\cdot 6{,}95\cdot 10^{8}\ \mathrm{s}^{-1}\cdot 395\ \mathrm{nH} = 12{,}35\ \mathrm{k\Omega}$$

Now we calculate the new real part of the source impedance R_{Source}:

$$R_{Source} = \frac{20\ \mathrm{k\Omega}\cdot 12{,}35\ \mathrm{k\Omega}}{20\ \mathrm{k\Omega} + 12{,}35\ \mathrm{k\Omega}} = 7{,}636\ \mathrm{k\Omega}$$

The new real part of the source admittance is therefore: $a_{in}=1/R_{Source}=1{,}3096*10^{-4}$ S. This values is now used for the calculation of the determinant and the new, more accurate matching elements:

$$D_{ps} = a_{in}\cdot a_{out}(a_{out}^2 - a_{in}\cdot a_{out} + b_{out}^2) = 8{,}4261\cdot 10^{-12}\ \mathrm{S}^4$$

$$B_{p-} = -\frac{\sqrt{D_{ps}}}{a_{out}} - b_{in} = -0{,}00348\ \mathrm{S} < 0 \Rightarrow L_{p-} = -\frac{1}{w_0\cdot B_{p-}} = 414\ \mathrm{nH} \quad \text{and}$$

$$X_{s-} = \frac{-a_{in}\cdot b_{out} - \sqrt{D_{ps}}}{a_{in}(a_{out}^2 + b_{out}^2)} = -417\ \Omega < 0 \Rightarrow C_{s-} = -\frac{1}{w_0\cdot X_{s-}} = 3{,}4\ \mathrm{pF}$$

Now, the difference between this element values and the exact ones should be as accurate, as the estimation of board parasitics. To obtain the starting values for hardware fine tuning, we transform the results to a balanced circuit according figure (12):

open collector bias coils: $L_{oc}=0{,}5*L_{p-}$=207 nH; chosen: 220 nH
serial matching capacitors: $C_{sm}=2*C_{s-}$=6,8 pF; chosen: 6,8 pF (or 7 pF)

Understanding the basic principles of SAW filter matching will help you apply modern simulation programs for the calculation of matching circuits. Of course, modern network simulation programs can calculate matching circuits with non-infinite quality factors of matching elements. The necessary scattering-parameters of SAW filters are being provided by Siemens Matsushita.

射频和天线设计培训课程推荐

易迪拓培训(www.edatop.com)由数名来自于研发第一线的资深工程师发起成立，致力并专注于微波、射频、天线设计研发人才的培养；我们于 2006 年整合合并微波 EDA 网(www.mweda.com)，现已发展成为国内最大的微波射频和天线设计人才培养基地，成功推出多套微波射频以及天线设计经典培训课程和 ADS、HFSS 等专业软件使用培训课程，广受客户好评；并先后与人民邮电出版社、电子工业出版社合作出版了多本专业图书，帮助数万名工程师提升了专业技术能力。客户遍布中兴通讯、研通高频、埃威航电、国人通信等多家国内知名公司，以及台湾工业技术研究院、永业科技、全一电子等多家台湾地区企业。

易迪拓培训课程列表：http://www.edatop.com/peixun/rfe/129.html

射频工程师养成培训课程套装

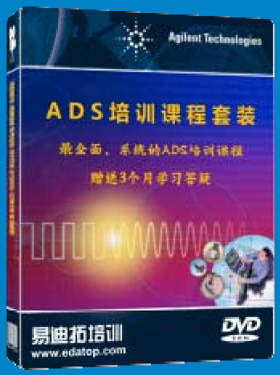
该套装精选了射频专业基础培训课程、射频仿真设计培训课程和射频电路测量培训课程三个类别共 30 门视频培训课程和 3 本图书教材；旨在引领学员全面学习一个射频工程师需要熟悉、理解和掌握的专业知识和研发设计能力。通过套装的学习，能够让学员完全达到和胜任一个合格的射频工程师的要求…

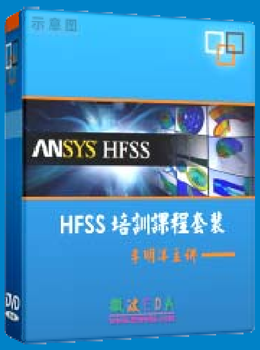
课程网址：http://www.edatop.com/peixun/rfe/110.html

ADS 学习培训课程套装

该套装是迄今国内最全面、最权威的 ADS 培训教程，共包含 10 门 ADS 学习培训课程。课程是由具有多年 ADS 使用经验的微波射频与通信系统设计领域资深专家讲解，并多结合设计实例，由浅入深、详细而又全面地讲解了 ADS 在微波射频电路设计、通信系统设计和电磁仿真设计方面的内容。能让您在最短的时间内学会使用 ADS，迅速提升个人技术能力，把 ADS 真正应用到实际研发工作中去，成为 ADS 设计专家...

课程网址： http://www.edatop.com/peixun/ads/13.html





HFSS 学习培训课程套装

该套课程套装包含了本站全部 HFSS 培训课程，是迄今国内最全面、最专业的 HFSS 培训教程套装，可以帮助您从零开始，全面深入学习 HFSS 的各项功能和在多个方面的工程应用。购买套装，更可超值赠送 3 个月免费学习答疑，随时解答您学习过程中遇到的棘手问题，让您的 HFSS 学习更加轻松顺畅…

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

CST 学习培训课程套装

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