Qualcomm
RF360
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Application Note SAW Components

How to choose the optimal SAW filter

App. Note 19

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Introduction

The number of radio services has increased much over the last decades. For one service the radiated signal of another service is an interferer. Therefore frequency filters are necessary for all reliable radio services. Surface acoustic wave filters are frequency filters suited from several MHz to 3 GHz, which protect the service from interferers and ensure that almost all of the wanted signal will be forwarded to the receiver input or the antenna.

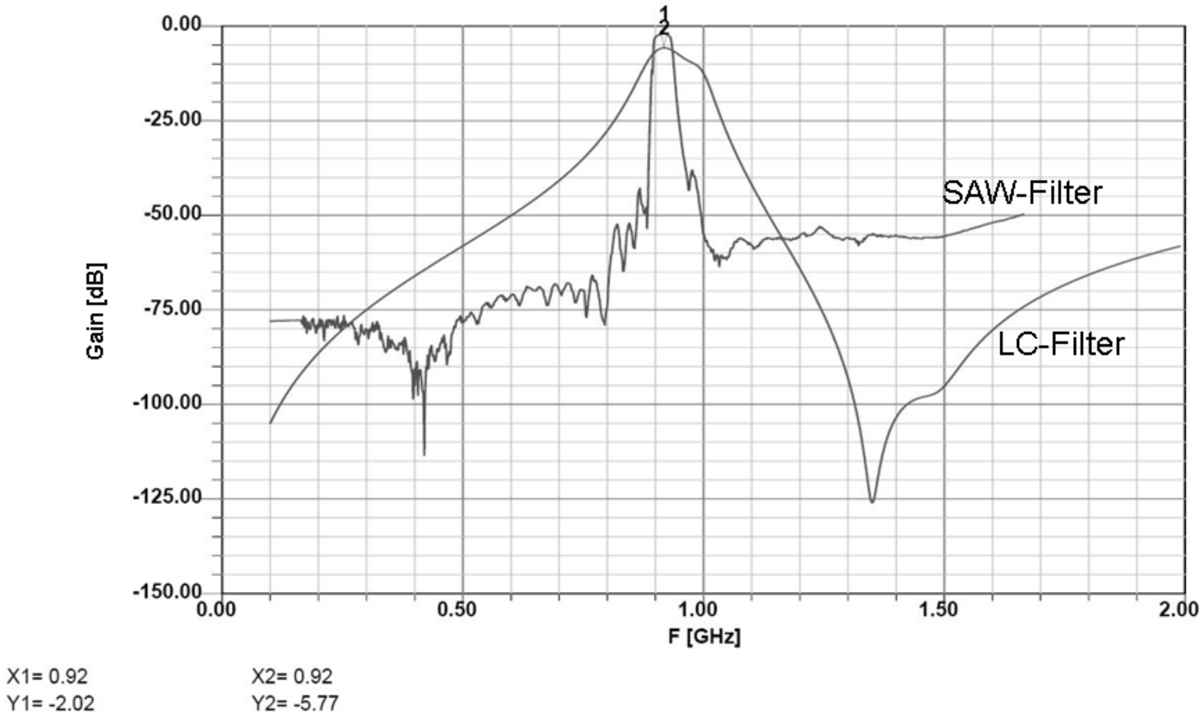

Figure 1: Performance of RF360 wide band filter (1) and discrete LC 3rd order Chebyshev filter (2)

In figure 1 a comparison of an RF360 wide band filter and a discrete LC filter are shown. The LC filter is composed of 3 inductors with quality factors of 55 @915MHz and 3 capacitors of quality factors of >35@915MHz.
It can be clearly seen that the SAW filter offers a better protection of the service because of the higher selectivity. Furthermore the signal is more efficiently transmitted to the receiver input or the antenna due to the lower insertion loss.

In transmitting RF systems SAW filters are used to suppress the radiation of undesired harmonics.
In receiving paths SAW filters improve the selectivity of the front-end. Image frequencies are rejected and powerful out-of-band interfering signals are blocked.

In the following text some keywords are *italicised*. These are key specification parameters shown in the respective SAW filter datasheets.

Criteria to choose a SAW filter

The application defines the SAW filter characteristics. For each application certain national or international regulations or end costumer specifications have to be considered:

- Frequency band
- Electromagnetic interference
- Bandwidth
- Sensitivity
- Maximum ratings, e.g. operable temperature
- Quality standards

Frequency band:

Each application works in one, sometimes in more frequency bands. A SAW filter is designed for a specific frequency, its *center frequency*. For example, for GPS applications the center frequency of the SAW filter would be 1575.42 MHz.
Each country has some frequency bands, in which short range RF systems are allowed to operate. For standardization reasons the Radiocommunication Sector of the International Telecommunication Union has defined the industrial, scientific and medical radio bands (ISM-bands), e.g. 433.05-434.79 MHz for Europe or 902-928 MHz for America. National regulations have to be regarded if there are additional bands available and what the respective technical requirements are. The most common institutions are the European Telecommunications Standards Institute (ETSI) and the Federal Communications Commission (FCC).

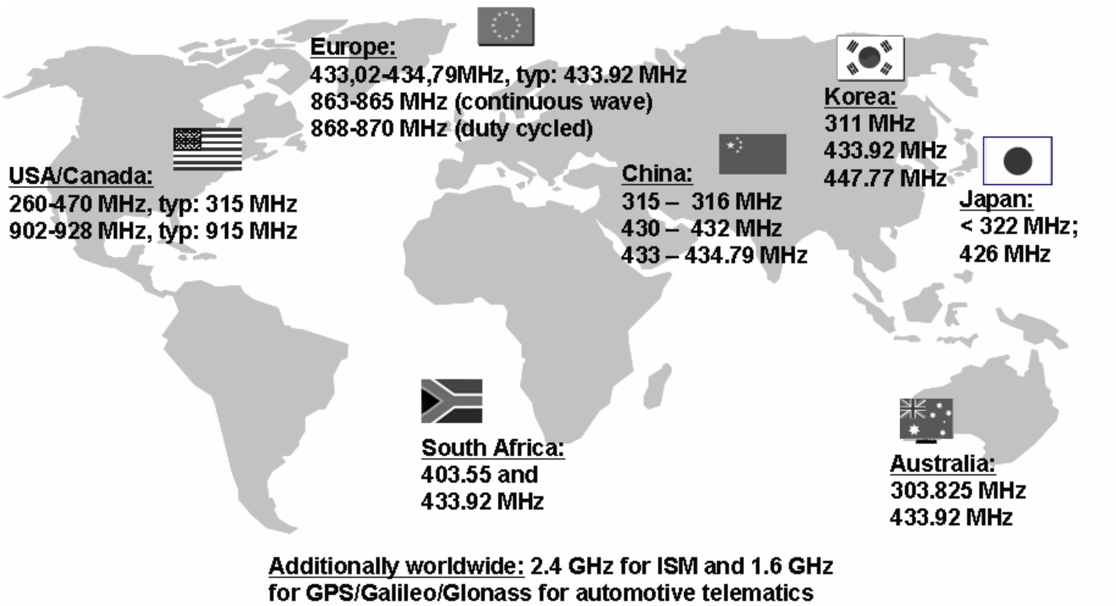

Figure 2: Common frequency bands used for short range applications

Electromagnetic interference:

The electromagnetic interference scenario, in which the system operates, will determine the required level of *attenuation* outside the pass-band of the SAW filter. The interferer situation has to be checked both in the used frequency band and in the close-by frequency bands.

Typical interferer for short range devices are:

Application	Services	Frequency band
Cellular communication	e.g. GSM 850	824-849MHz (UL) 869-894MHz (DL)
	e.g. WCDMA Band 4	1710-1755MHz (UL) 2110-2155MHz (DL)
	....	...
Two way trunk radio	e.g. Tetra	e.g. 420-430MHz
Personal area network	e.g. RFID	868-928MHz
Local area network	IEEE 802.12x	2.4-2.4835GHz
Mobile Video Broadcasting	DVB-H	e.g. 470-582MHz

Table 1: Examples of some potential interferer services

In most cases one channel is used to transmit the data. This has the advantage that the bandwidth of the SAW filter can be very narrow and a very high selectivity can be achieved.
Sometimes more than one channel is used to transmit the data. The advantage is that although there is an in-band interferer on one channel, the data can still be correctly transmitted, if the same data is transmitted on a second or third channel. The disadvantage is that the close-by selectivity is decreased because of the needed wider bandwidth of a multichannel SAW filter.

Bandwidth

The *usable bandwidth*, which is correlated with the transmitting bandwidth, can be calculated by looking at the highest and lowest possible frequency of the transmitting signal.
The frequency of the transmitting signal varies due to the production tolerances, temperature shift, aging, variation of the operating voltage and the modulation spectrum of the transmitter.
The usable bandwidth of the respective filter is specified in the datasheet. The real filter bandwidth measured @+25°C is larger due to production tolerances and frequency drift over the temperature range, in which the SAW filter is specified.

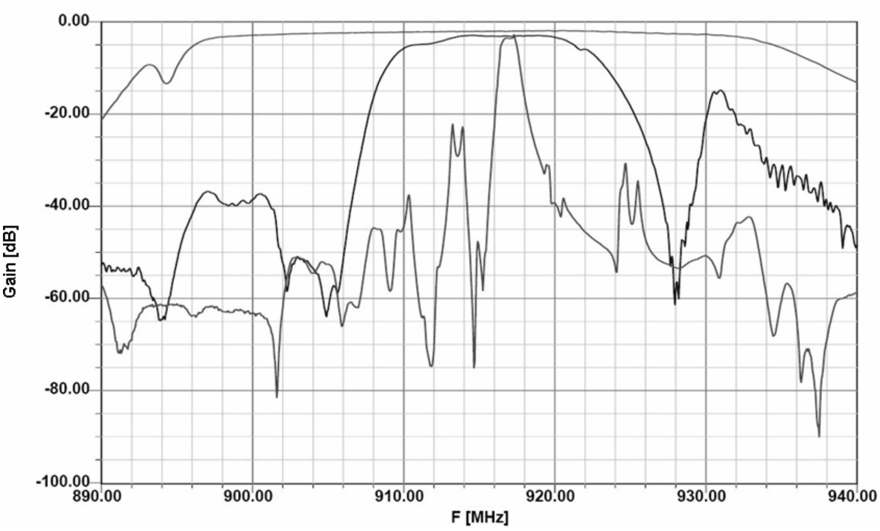

Figure 3: Bandwidths of wide-, narrow- and ultra-narrow SAW filters

In general it is possible to offer SAW filters of different bandwidths as different piezoelectric substrate materials can be used, e.g. quartz or lithium tantalate.

bandwidth	substrate	temperature coefficient	usable bandwidth	impedance
ultra-narrow	quartz	-0,032 ppm/K² (parabolic)	~ 100...120 kHz	~ 400...800 0
narrow	quartz	-0,032 ppm/K² (parabolic)	~ 300...1100 kHz	~ 250...800 0
wide	tantalate	~ -35 ppm/K (linear)	~ 600...26000 kHz	50 0 or customer specific

Table 2: Substrate comparison of quartz and tantalate

Using quartz substrate filters can be designed with a very small usable bandwidth. Also the temperature shift is smaller, but input and output impedances are higher than 50Ω and have a capacitive contribution. Using tantalate as a substrate, 50Ω input and output impedances are possible, but the usable bandwidth is wider and the temperature shift of center frequency is higher.

Special attention must be paid to the image frequency. For a superheterodyne Rx system working at e.g. 315MHz and using 10.7MHz as the intermediate frequency the image frequency would be 315MHz + 2 * 10.7MHz=336.4MHz, if the system operate with high side injection. Signals at this frequency will be transferred to the demodulator and would superimpose to the wanted signal. Therefore the attenuation at the image frequency is very important.

The far-off selectivity is very good for most SAW filters, but the matching topology, low, high or band pass, has a major influence at high frequencies.

Sensitivity:

The customer specification requires a certain sensitivity. The sensitivity describes the ability of the receiver to receive weak signals. Therefore it is important to keep the losses in the front-end as low as possible. The *insertion attenuation* of the SAW filter has a strong impact on the sensitivity.
For worst case calculations the maximum insertion loss of the SAW filter is the minimum insertion loss plus the ripple in the transmitting bandwidth (narrowband filter) or the value directly stated in the datasheet as maximum insertion loss for the corresponding bandwidth (wideband filter).

For each receiver IC the sensitivity is specified by a certain signal input power level for which the IC is able to decode the signal correctly. As an example a transmitter radiates a signal with the power of -40dBm. The signal is attenuated in the air by -25dB and the antenna gain of the receiver unit is -15dB. If the receiver's sensitivity level is specified with -85dBm, then there are 5dB insertion loss for the link between antenna and receiver IC: 5dB = (-40dBm -25dB -15dB)-(-85dBm). If the SAW filter has a maximum insertion loss in the transmitting bandwidth of -3dB, there would be 2dB for losses in the matching networks.

Maximum Ratings

The maximum ratings concern the *operable and storage temperature*, the maximum *source power* and the *DC voltage*.
The power handling capability of the SAW filter must be verified. Continuous signals at the highest operable temperature can be applied over the whole lifetime. With lower duty cycle over a shorter time period signals of a higher power level can be applied without direct failure of the SAW filter. These specific values must be requested separately, if not specified in the datasheet.
In some circuits the SAW filter is also used as a DC Voltage blocker. Typical values of DC blocking are 0-6V.

Quality standards:

Here we can distinguish automotive qualified and non automotive qualified SAW filters. In the datasheet it is specified if a SAW filter belongs to an *AEC-Q200* qualified family, a qualification standard of the Automotive Electronics Council.
It is also stated in the datasheets that RF360 SAW filters are compatible with lead free soldering as specified in J – STD20C, a standard of the JEDEC Solid State Technology Association, and that RF360 SAW filters follow the RoHS directive, an European Union directive on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment.

Simulation of SAW filter

System calculation with a circuit simulator

For all SAW filters S-parameter files in the touchstone file format, *.snp, are available.
In a first step ideal matching elements can be taken, but they should be replaced by models of real matching elements. Transmissions lines should also be taken into account in a second step of the simulation process.
A simulation taking into account parasitic effects will help to shorten the time in the laboratory to find the best matching values.

SAW Filter Technology

A SAW (surface acoustic wave) filter's functionality is based on the piezoelectric effect. That means, when imposing pressure on a piezoelectric substrate, mechanical energy is transformed into electrical energy and vice versa. See figure 4 for this principle.

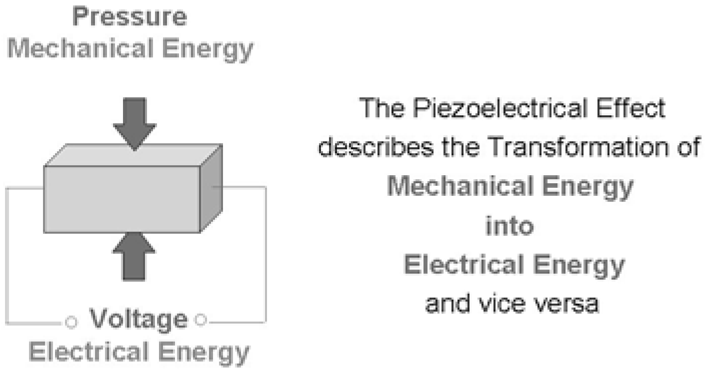

Figure 4: Explanation of piezoelectric effect

A geometrical structure, like it is shown in figure 5, is deposited on a piezoelectric substrate. The geometry creates the surface acoustic wave.

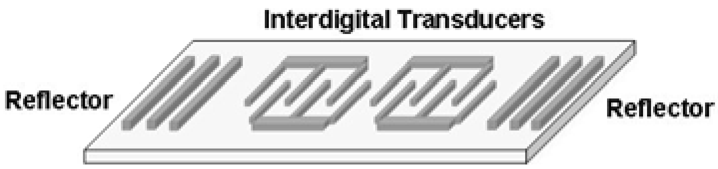

Figure 5: Schematic diagram of a SAW component

As the dimension of the structure is inversely proportional to the frequency of the wave, a wave frequency less than 1 MHz is problematic concerning chip space – wave frequencies above 3 GHz need finer structures than industry is able to produce.

The transformation of electrical into mechanical energy offers the following advantages:

- The geometrical structure offers has a very high filter characteristic
- The reproducibility of the structure is very high as well
- The acoustic wavelength is much smaller compared to the electrical wavelength, which allows very small device dimensions of the piezoelectric chip.

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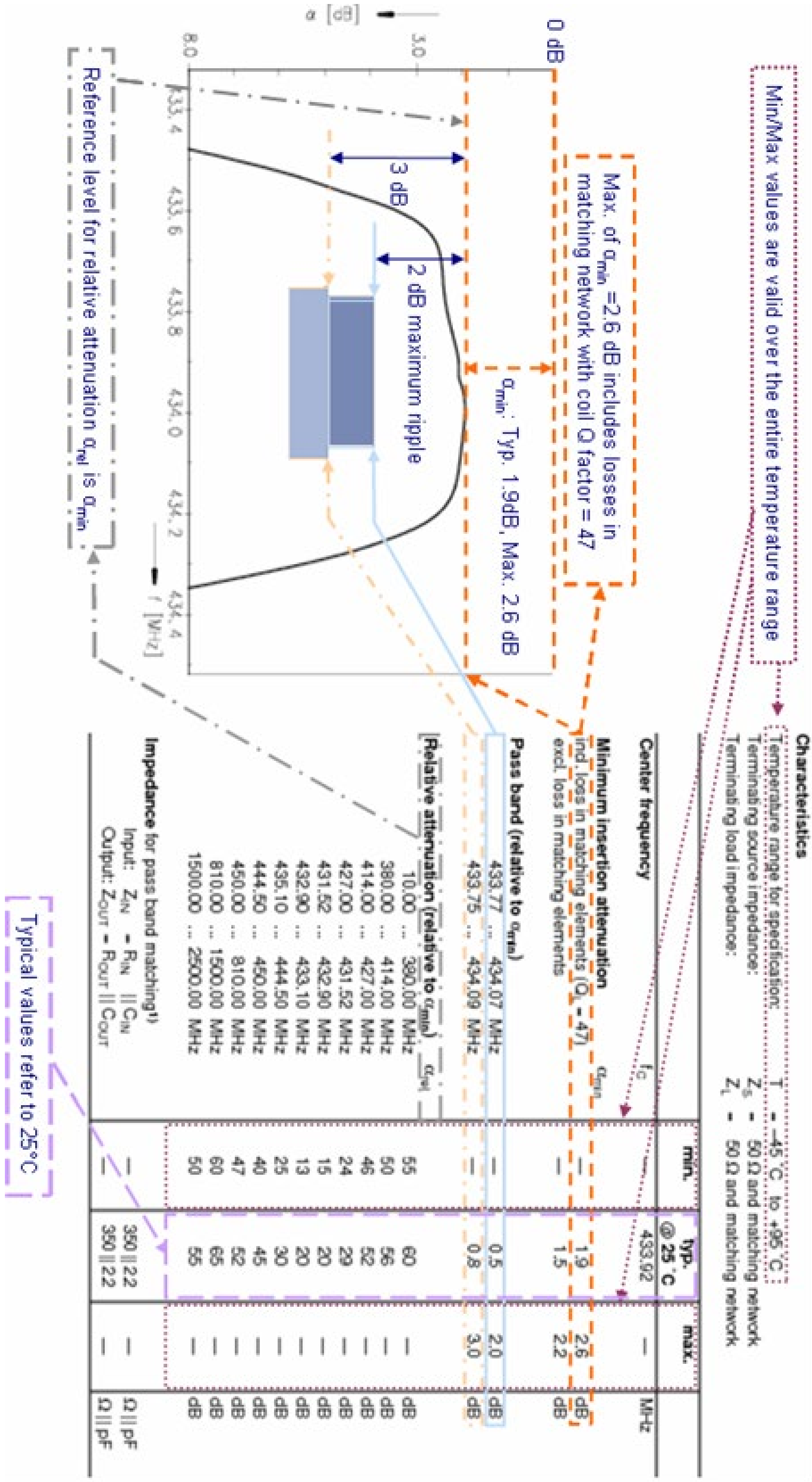
Annexe – Data Sheets Explained: Narrow-band filter (Quartz substrate)



Annexe – Data Sheets Explained: Wide-band filter (Tantalate substrate)