AN072
Using the TAI-SAW TA0801A SAW Filter and External PA with the CC11xx Radios in the 868 MHz Band

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Keywords

- *SAW (Surface Acoustic Wave) Filter*
- *CC1101, CC1110, CC1150, CC430*
- *ETSI (European Telecommunications Standards Institute) Compliance*
- *868 MHz*

Introduction

Surface Acoustic Wave (SAW) filters are often used in radio communication due to their excellent frequency response characteristics, controlled impedance, power handling, and small form factor.

SAW filters offer a steep frequency roll-off and high stop-band attenuation which rejects unwanted harmonics from the radio and unwanted blockers from nearby frequency bands.

This application note will examine using the TAI-SAW TA0801A SAW filter with the CC11xx series radios and an external power amplifier to increase performance while maintaining ETSI compliance[1].

Filter response of the TA0801A and spectral performance of the CC11xx with external power amplifier with and without the SAW filter will be shown.

Tradeoffs of output power, complexity, sensitivity, sensitivity to load variation and power consumption will be examined.

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Overview of TAI-SAW TA0801A

The TA0801A SAW filter offers a minimum of 22 dB of attenuation up to 850 MHz and 27 dB above 885 MHz. This particular device is rated for 50,000 hours at +18 dBm input power allowing it to be used after a power amplifier. Additional information on the TA0801A can be obtained from TAI-SAW[2].

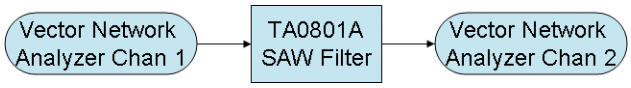

Figure 1. Measurement Setup

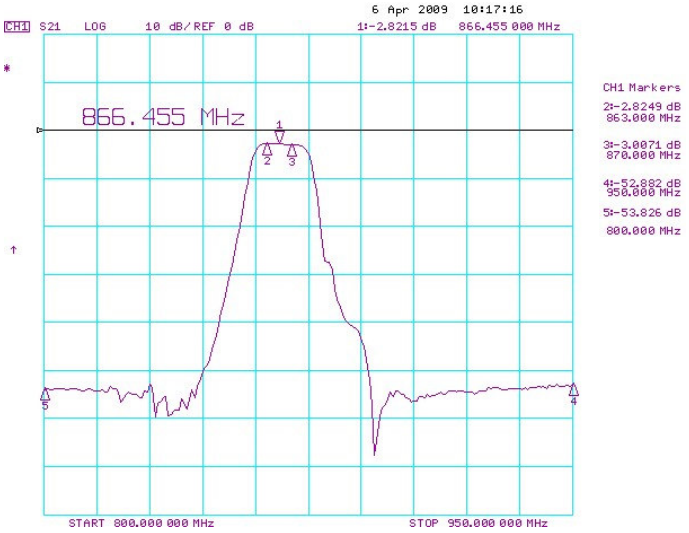

Figure 2. TA0801A Filter Characteristics - Passband

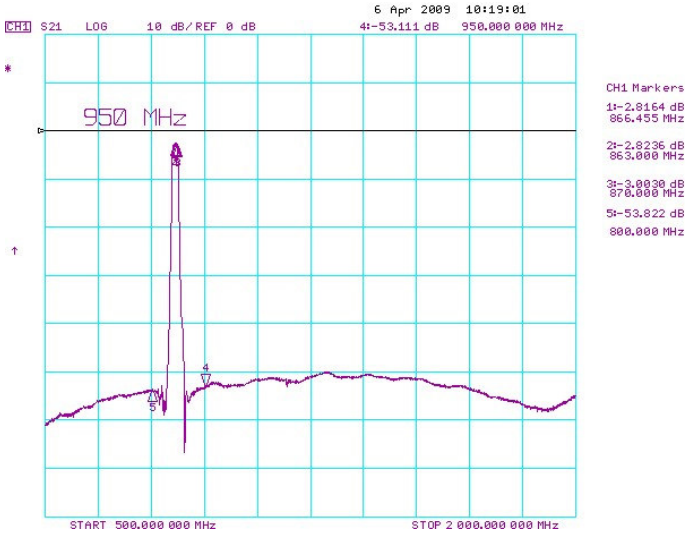

Figure 3. TA0801A Filter Characteristics

CC1150 Radio with external PA

For this test, the CC1150 is connected to an external power amplifier (PA). The PA used provides 16 dB of gain. The output power of the CC1150 is set such that the PA output achieves a measured level of +14 dBm. This corresponds to a register setting of 0x3D or -3.2 dBm at 868 MHz[5].

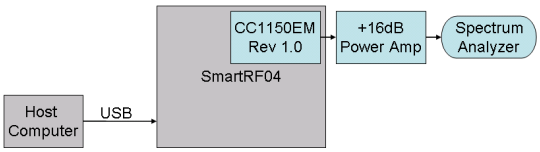

Figure 4. Measurement Setup

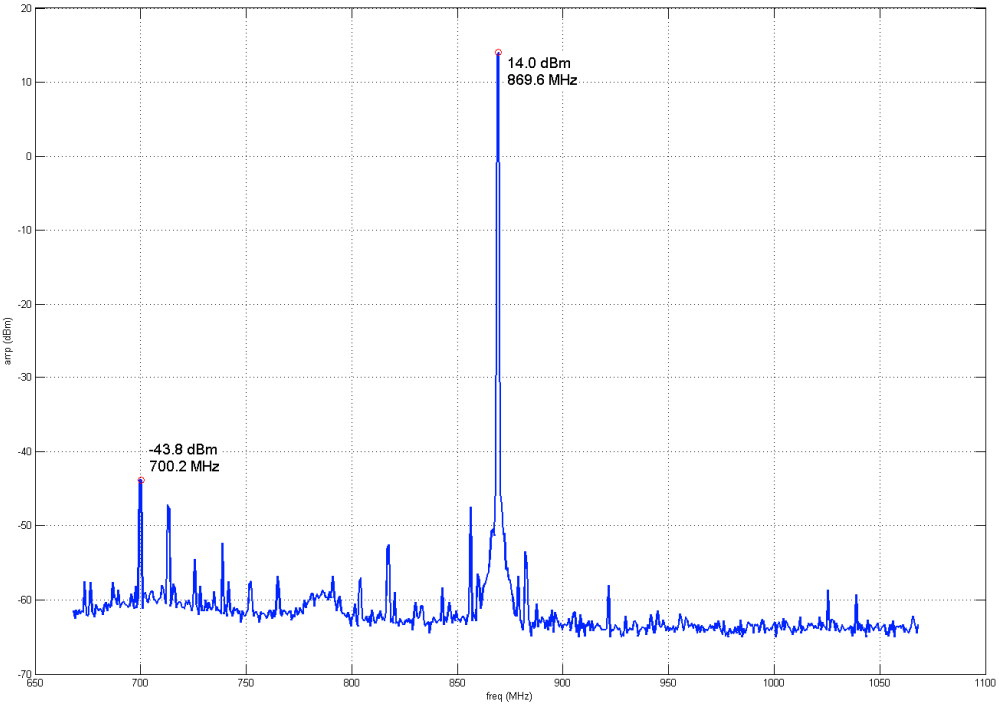

Figure 5. CC1150 Performance with External PA at +14 dBm Output Power without SAW Filter

Since the amplifier is a wideband PA it amplified the spurs of the CC1150 along with the desired signal. When doing conducted measurements the spurs of the overall system now exceed ETSI regulation limits of -54 dBm by more than 10 dB.

CC1150 Radio with TA0801A SAW and External PA

To attain +14dBm output power with the SAW filter in place, the CC1150 with PA is set to a power level of 0x53 or -2.3 dBm[5]. With the external PA this correlates to an output power of +15.8 dBm without the SAW filter.

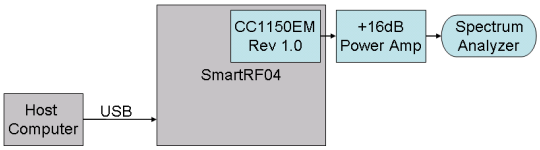

Figure 6. Measurement Setup

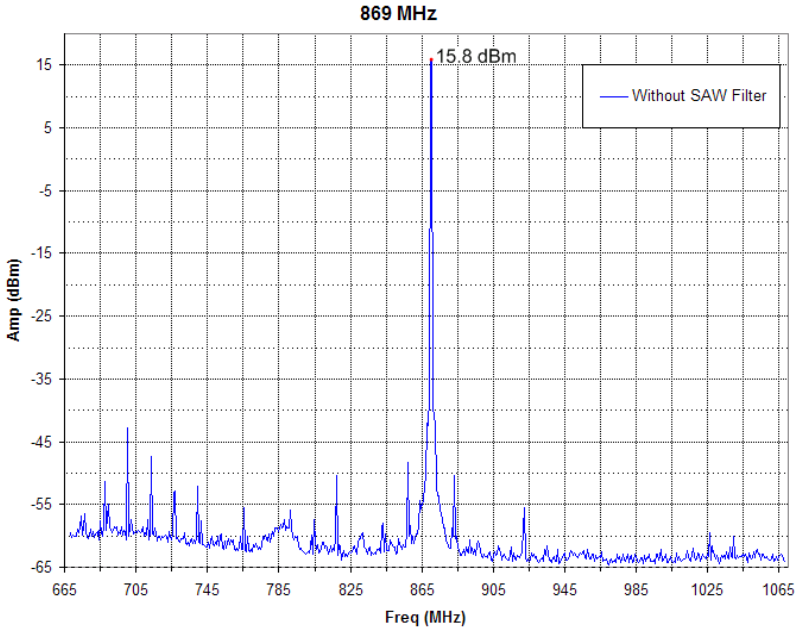

Figure 7. CC1150 Performance with External PA at +15.8 dBm Output Power without SAW Filter

CC1150 Measurement with PA, SAW and ETSI Limits

When the SAW filter is added after the PA, there is a dramatic reduction of out of band noise and spurs.

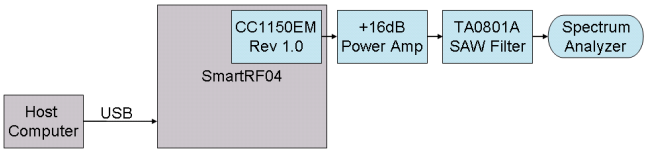

Figure 8. Measurement Setup

Figure 9 shows measurements with PA and SAW filter with the ETSI limits superimposed:

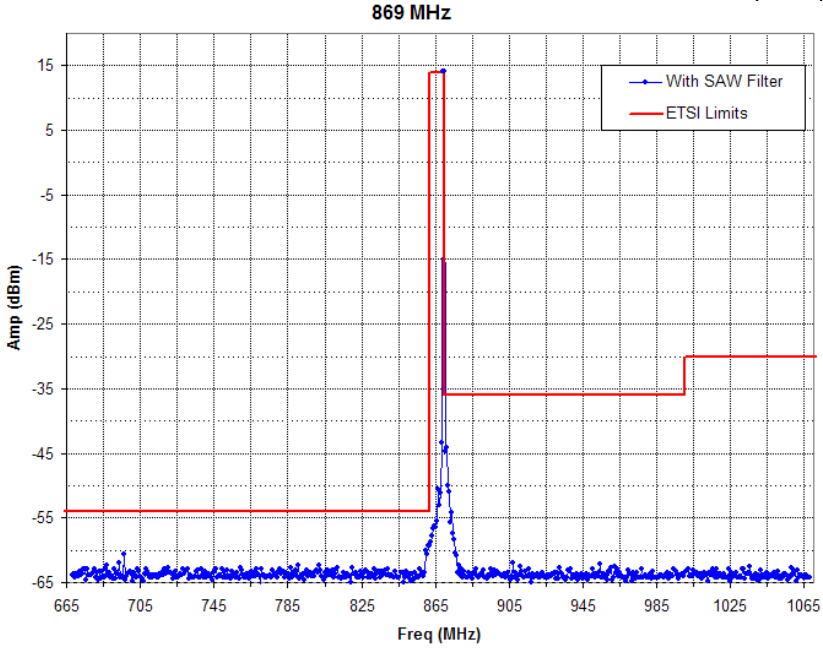

Figure 9. CC1150 with External PA and SAW Filter and ETSI Limits

Figure 10 shows a magnified trace of the response at 868.2 MHz through the SAW filter with the ETSI limits superimposed:

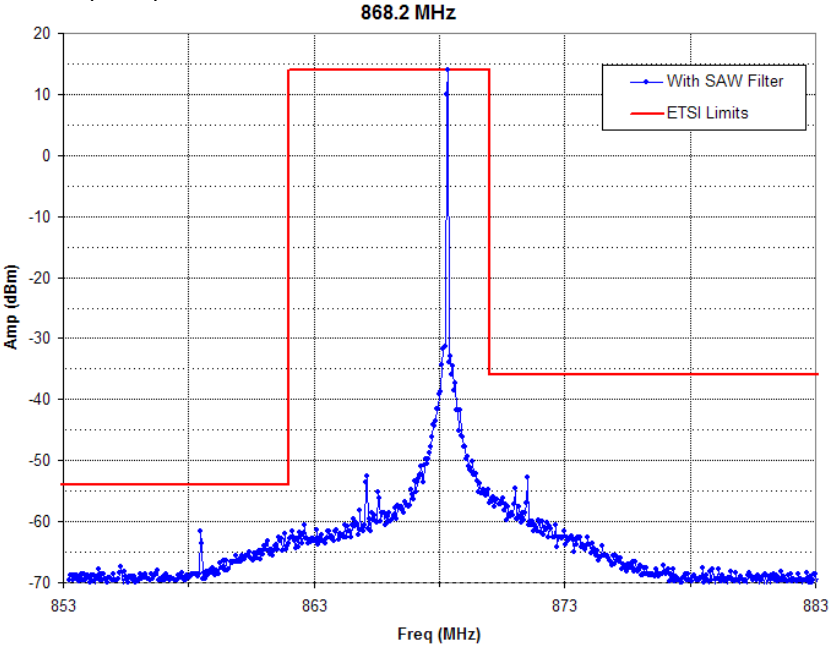

Figure 10. CC1150 with External PA and SAW Filter and ETSI Limits - Magnified

The device should now easily pass ETSI requirements for out of band noise.

Sensitivity Testing

When using the SAW filter on the input of a receiver, the filter will absorb some of the input power causing the system to have a lower overall sensitivity. The sensitivity of the CC1101 was measured with and without a SAW filter on the input of the device. The following results were obtained from CC1101EMs on the SmartRF04 boards. Absolute attenuation through the signal chain was not verified and as such the results should be taken as relative to each other.

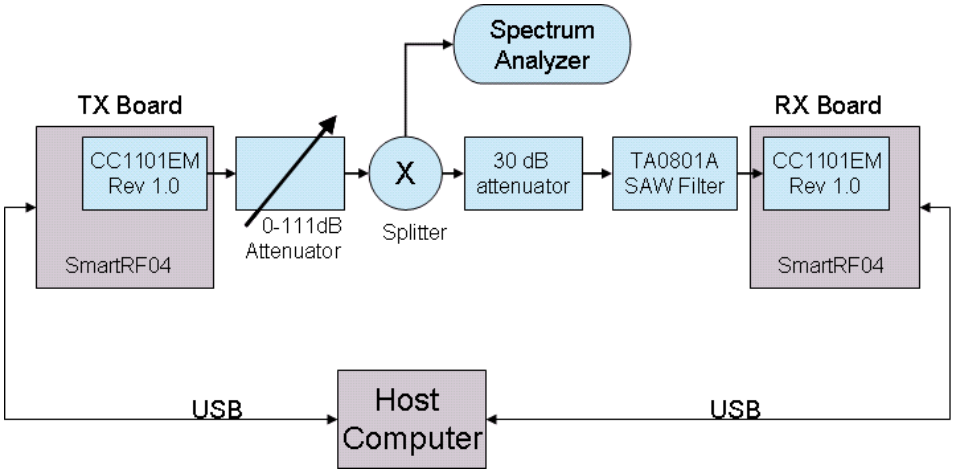

Figure 11. Measurements Setup with a SAW Filter on the Receiver

The purpose of the measurement is to determine the carrier strength needed to achieve a packet error rate of 1%. The measurement was performed as follows:

1) The spectrum analyzer is setup for a resolution bandwidth of 1 kHz. This value is chosen to integrate as much carrier power as possible while minimizing integration of noise.
2) The Transmit board is setup to transmit at 0 dBm output power at 868 MHz, un-modulated carrier.
3) Since the datasheet sensitivity of the CC1101 is -94 dBm when operating at 868 MHz and 250 kBaud[6], we set the 0-111 dB attenuator such that the measured power delivered to the load is at least 3 or so dB higher than that value. This was accomplished by setting the attenuator to a given value, such as -50 dB then measuring the power on the spectrum analyzer. By subtracting 30 dB from this value we can determine roughly what the power delivered to the RX board is.
4) Record the power measured on the spectrum analyzer.
5) Perform a "Packet TX/RX" test using SmartRF® Studio. Set the packet length to 20 and the packet count to 1000 packets.
6) Record the packet error rate achieved.
7) Increment the 0-111dB attenuator by 1 dB and perform steps 4-7 until a packet error rate of less than 1% is obtained.
8) Redo steps 2-7 first at 863 MHz, then at 870 MHz.
9) Repeat steps 2-8 without the SAW filter on the RX side.

Sensitivity Results

	Receiver Power	Change from Base
CC1101 Base Sensitivity	-91.5 dBm*	0 dB
with SAW Filter on Receiver	-89.2 dBm	-2.3 dB

Table 1. CC1101 Sensitivity (Packet Error Rate of 1%)

* Absolute attenuation through the signal chain was not verified and as such the results should be taken as relative to each other.

The procedure limits the sensitivity measurement accuracy to steps of 1 dB. As these results show, using the SAW filter on the receiver will cause loss of sensitivity roughly equal to the insertion loss of the filter. A sensitivity loss equal to the insertion loss of the filter means that additional phase distortion is not a concern. Phase distortion would show up as a higher than expected loss of sensitivity.

Power Consumption

One trade-off of using a SAW filter is the additional power dissipated in the filter. To counteract this, the output power of the radio must be increased to compensate for the insertion loss of the filter. Alternatively, the same output power can be used and the system architect can deal with the decreased range. This test shows the increased supply current used to achieve the same overall output power when the SAW filter is added to the output of the radio.

To measure the power consumed a CC1150EM V1.0 was modified with a 1 ohm resistor in series with L1, the ferrite bead that connects the EM power to the SmartRF04 board. The CC1150 was then placed in un-modulated carrier output mode and the current consumption was read with a multimeter.

	Overall Output Power		
	0 dBm	**+7 dBm**	**+10 dBm**
CC1150	15.5 mA	23.7 mA	28.5 mA
CC1150 with SAW	17.1 mA	27.1 mA	
Δ current	+1.6 mA	+3.4 mA	

Table 2. Supply Current with and without SAW Filter

To achieve the same output power, the radio consumes an additional 1.6 – 3.4 mA of current.

Sensitivity to Load Variation

An additional benefit to using a SAW filter is the decreased sensitivity to load variations. The current consumption of the CC11xx radios will vary with antenna impedance fluctuations. If a SAW filter is used, the impedance variation that the radio "sees" will be minimized. This lessens changes in current consumption. Closely controlled current consumption is especially important if accurate battery life predictions must be made in a dynamic environment.

	Maximum Increase in Current Consumption
Without SAW Filter	+7.7 mA
With SAW Filter	+1.9 mA

Table 3. Supply Current Fluctuations with and without SAW Filter

Conclusions

A SAW filter is most valuable in systems that require the following criteria:

1. High output power is required.
2. Additional out of band filtering is needed in the receiver.
3. Decreased sensitivity to load variation is required.

The following are drawbacks to adding a SAW filter:

1. More expensive.
2. Additional board space is required.
3. The SAW absorbs transmit power which increases system power consumption.
4. The SAW absorbs received power which lowers overall system sensitivity.

There are two likely applications for the TA0801A:

1. Single Direction Transmission with SAW on transmit side only:
   When using the SAW on the transmit side only, the transmitter will be able to increase output power with a corresponding increase in link budget. The system will not benefit from the increased rejection of out of band blockers provided by the SAW filter.

2. Bi-Directional Transmission with SAW on transmit and receive:
   The SAW on the transmit side will allow the increase in output power from to +14 dBm. However, the SAW on the receiver will absorb ~2.5 dB of this power yielding a net increase in link budget of only ~1.5 dB. Additionally, the system will benefit from the enhanced rejection of out of band blockers provided by the SAW filter.

In conclusion, the SAW filter offers the most benefit in unidirectional systems that require longer range while maintaining ETSI compliance or bi-directional systems that need additional out of band filtering while maintaining range and ETSI compliance.

References

[1] ETSI standards and information available at http://www.etsi.org/WebSite/homepage.aspx.

[2] Additional information available at http://www.taisaw.com/.

[3] CC1101 Development Kit 868-915MHz schematic available on the TI web at http://focus.ti.com/docs/toolsw/folders/print/cc1101dk868-915.html.

[4] See AN050 - Using the CC1101 in the European 868MHz SRD band is available on the TI web at: http://focus.ti.com/analog/docs/techdocsabstract.tsp?familyId=368&abstractName=swra146a.

[5] See DN013 – Programming Output Powers on the CC1101 for more information on programming the CC1150 in finer power output steps: http://focus.ti.com/analog/docs/techdocsabstract.tsp?familyId=935&abstractName=swra151a.

[6] See CC1101 datasheet, available on the TI web at http://focus.ti.com/docs/prod/folders/print/cc1101.html.

Document History

Revision	Date	Description/Changes
SWRA296	2009-06-30	Initial release.
SWRA296A	2009-08-19	Revised Keywords

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