WHITE PAPER

Improving Wi-Fi Range and Capacity with Qorvo edgeBoost™ Filters

Abstract

Qorvo edgeBoost filters, also known as bandedge BAW filters, improve Wi-Fi range and capacity by allowing Wi-Fi systems to maintain maximum RF output power on all channels in the 2.4 GHz Wi-Fi band. They solve a key challenge for Wi-Fi system engineers: how to maximize output power on all non-overlapping Wi-Fi channels while meeting strict FCC (Federal Communications Commission) limits for emissions in restricted bands. In the 2.4 GHz Wi-Fi band, only three non-overlapping channels are available in the U.S.: channels 1, 6, and 11. Without BAW filters, systems need to back off output power in channels 1 and 11 to meet FCC regulatory requirements, significantly reducing range and capacity. Qorvo edgeBoost filters have steep skirts that allow the system to operate at rated power in channels 1 and 11 without violating FCC limits; this typically regains 6-10 dB of power, which can increase range by 100% or even more. There are multiple filter solutions that exist, but only Qorvo supplies 2.4 GHz bandedge BAW filters that address this issue in its entirety.

Introduction

Over the years, the IEEE (Institute of Electrical and Electronics Engineers) has developed new standards to progressively address the worldwide advancement of Wi-Fi, as shown in Table 1. Each IEEE 802.11 Wi-Fi protocol operates within specific frequencies, known as ISM (Industrial, Scientific and Medical) unlicensed bands. These bands are free of licensing restrictions, but they are shared among Wi-Fi users and with a variety of other non-Wi-Fi devices and users.

Table 1: Summary of IEEE 802.11 protocol evolution and features.

IEEE 802.11 Protocol	Release Date	Frequency Band(s) (GHz)	Bandwidth (MHz)	Max Throughput
801.11 – 1997	1997	2.4	22	2 Mbps
11b – Wi-Fi 1	1999	2.4	22	11 Mbps
11a – Wi-Fi 2	1999	5	20	54 Mbps
11g – Wi-Fi 3	2003	2.4	20	54 Mbps
11n – Wi-Fi 4	2009	2.4/5	20/40	600 Mbps
11ac – Wi-Fi 5	2013	2.4/5	20/40/80/160	6.8 Gbps
11ax – Wi-Fi 6	2019	2.4/5	20/40/80/160	10 Gbps

While the advances in Wi-Fi standards have increased the maximum data rate from 2 Mbps to 10 Gbps, each advance also adds complexity, making Wi-Fi product design more difficult. Adding to the challenge is the need to meet U.S. FCC limits on emissions in restricted or forbidden bands. Table 2 below lists the FCC 15.205 restricted band limits (stated in 47CFR 15.247) for the 2.4-2.5 GHz frequency band. The FCC limits allow a maximum of 1-Watt RF output power and up to a +6 dBi antenna gain on Wi-Fi channels within the operating band. Additionally, products must also comply with limits for power leakage in restricted bands below and above the operating band. This regulation makes it difficult for Wi-Fi product designers to achieve optimal transmit power across all usable Wi-Fi channels within the 2.4-2.5 GHz band.

Table 2: FCC restricted bands of operation.

Restricted bands of operation (FCC 15.205)

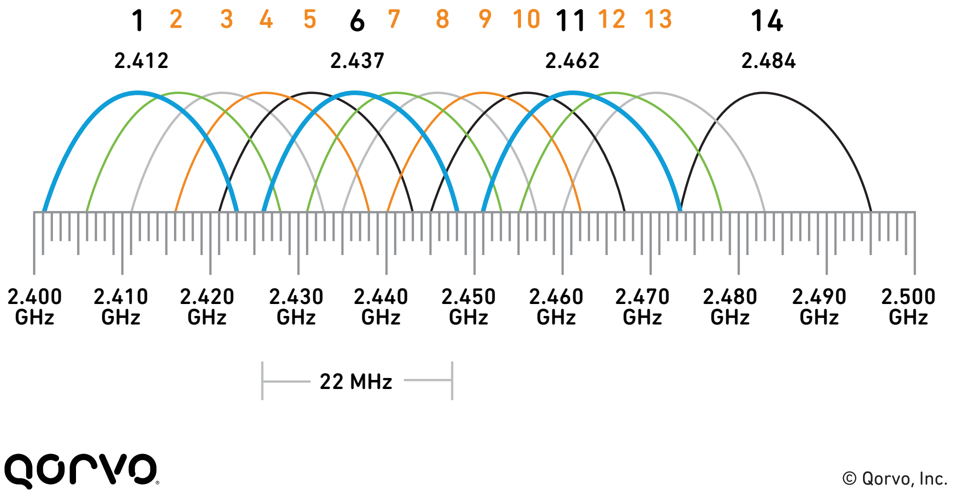
MHz	MHz	MHz	GHz
0.090-0.110	16.42-16.423	399.9-410	4.5-5.15
[1]0.495-0.505	16.69475-16.69525	608-614	5.35-5.46
2.1735-2.1905	16.80425-16.80475	960-1240	7.25-7.75
4.125-4.128	25.5-25.67	1300-1427	8.025-8.5
4.17725-4.17775	37.5-38.25	1435-1626.5	9.0-9.2
4.20725-4.20775	73-74.6	1645.5-1646.5	9.3-9.5
6.215-6.218	74.8-75.2	1660-1710	10.6-12.7
6.26775-6.26825	108-121.94	1718.8-1722.2	13.25-13.4
6.31175-6.31225	123-138	2200-2300	14.47-14.5
8.291-8.294	149.9-150.05	2310-2390	15.35-16.2
8.362-8.366	156.52475-156.52525	2483.5-2500	17.7-21.4
8.37625-8.38675	156.7-156.9	2655-2900	22.01-23.12
8.41425-8.41475	162.0125-167.17	3260-3267	23.6-24.0
12.29-12.293	167.72-173.2	3332-3339	31.2-31.8
12.51975-12.52025	240-285	3345.8-3358	36.43-36.5
12.57675-12.57725	322-335.4	3600-4400	([2])
13.36-13.41	–	–	–

[1] Until February 1, 1999, this restricted band shall be 0.490-0.510 MHz
[2] Above 38.6

Some Background: Wi-Fi Channels, Range and Capacity

Wi-Fi channels - The IEEE 802.11 allows roughly 80 MHz of bandwidth in the 2.4 GHz band in devices designed for worldwide use. However, in the U.S., the FCC limits the usable bandwidth to 70 MHz, divided into 11 20 MHz overlapping channels. These channels are just 5 MHz apart, and only three are non-overlapping: channels 1, 6 and 11. (see below Figure 1) Because channels 1, 6 and 11 are non-overlapping they are used the most, as it reduces possible interference between channels.

Figure 1: Non-overlapping Wi-Fi channels 1, 6, 11.



Range and capacity - A very important criterion for a Wi-Fi unit is RF range. The parameter most closely related to range is Wi-Fi output power. In the U.S., the most challenging design task is meeting FCC limits for spurious emissions in the restricted bands. To meet these limits, output power must be backed off in the 2.4 GHz lower and upper Wi-Fi channels (channels 1 and 11). This reduces capacity and range in these channels, resulting in performance degradation for users. Providing a way in which no back off is required will create a more optimum outcome for meeting range and capacity.

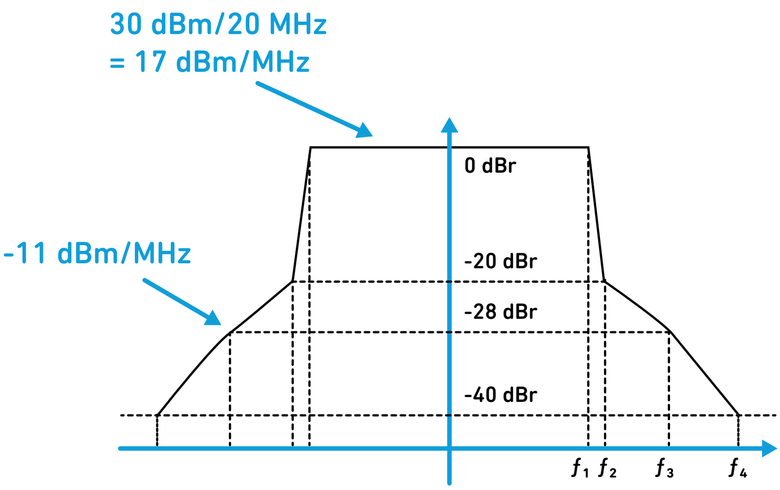
Spectral Masks vs. Bandedge Tests

One question that bothers many RF system engineers is: ‘My Wi-Fi system passes the IEEE 802.11 spectral mask tests, so why do I need to lower output power as much as 10 dB to pass the FCC bandedge regulation tests? Is there a difference between these two tests?’

Let’s explore this a bit further. The spectral mask test is part of the IEEE 802.11 standard. It sets limits for how much power from the in-band channels is allowed to leak into the adjacent channels. It is mainly a measure of interference within the Wi-Fi band. Bandedge testing is an FCC requirement that measures how much power leaks outside of the operating band into the restricted bands (2310-2390 MHz and 2483.5-2500 MHz). The question is, why doesn’t passing the IEEE spectral mask test guarantee a green light on FCC bandedge testing? The short answer is that the FCC bandedge regulation is a tougher specification to meet. To fully qualify your product this specification must be met.

Let’s look at an example. In a typical Wi-Fi system, spectral regrowth is due to both the Wi-Fi chipset and the amplifier in the transmit chain (mostly caused by the amplifier). For an amplifier operating on channel 1 centered at 2412 MHz with a 20 MHz bandwidth signal capable of delivering 30 dBm output power (per FCC regulations), power density is 17 dBm/MHz. To meet the IEEE Wi-Fi 5 spectral mask specifications, spectral regrowth at -20 MHz (2392MHz, f3 in Figure 2 below) needs to be lower than -11 dBm/MHz. At 2390 MHz, the spectral mask limits are -13.4 dBm/MHz. In contrast, the FCC’s bandedge limit is much lower, at -41.25 dBm/MHz. Thus, the FCC bandedge limit is a much tougher test, requiring spectral regrowth that is about 30 dB lower in this example. The same calculation also applies to channel 11 centered at 2462 MHz.

Figure 2: IEEE Wi-Fi Spectral Mask.



Channel Size	f_1	f_2	f_3	f_4
20 MHz	9 MHz	11 MHz	20 MHz	30 MHz
40 MHz	19 MHz	21 MHz	40 MHz	60 MHz
80 MHz	39 MHz	41 MHz	80 MHz	120 MHz
160 MHz	79 MHz	81 MHz	160 MHz	240 MHz

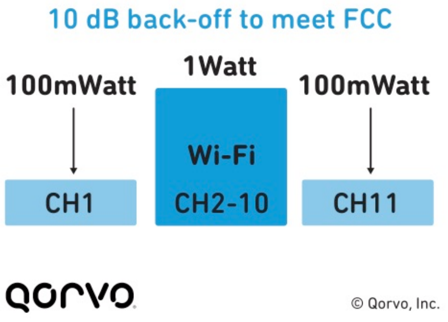
How do system designers overcome the bandedge output power problem?

Traditionally, there have been two approaches to solving this issue.

- The first is to avoid using edge channels altogether (channels 1, 2, 10 and 11), and use only the center channel (channel 6). However, this approach creates yet more network traffic in channel 6, which is already crowded.
- The second option is to lower in-band transmit power for the edge channels until the power leaking into the FCC restricted bands is within the FCC limits. This usually implies 8-10 dB lower transmit power on the edge channels than the center channels, as shown in Figure 3 below. It is common knowledge that lowering the power by 6 dB cuts the Wi-Fi range by half. In some cases, linear power is reduced by as much as 10 dB, with an even bigger negative effect on system range and capacity.

Obviously, neither of the above approaches are good solutions because they load the channels unevenly, limit system capacity and reduce the useful range of the Wi-Fi router.

Figure 3: Back-off in edge channels to meet FCC regulations.



A better solution: RF filters

Fortunately, there is a better solution to the problem: RF filters. These filters pass the ISM frequency band and attenuate out-of-band (OOB) signals. These are some of the most common types of filters used in the 2.4 GHz ISM band:

- Dielectric-resonator
- Surface acoustic wave (SAW)
- Bulk acoustic wave (BAW)
- Film bulk acoustic resonator (FBAR)

What is the best filter for this application?

When selecting a filter to solve Wi-Fi bandedge problems, it is important to consider the following parameters:

- Low in-band insertion loss
- High out-of-band attenuation (rejection)
- High power-handling capability
- Low non-linearity (harmonics generated by the filter)
- Low TCF (TCF – temperature coefficient of frequency)
- Small footprint
- Low cost

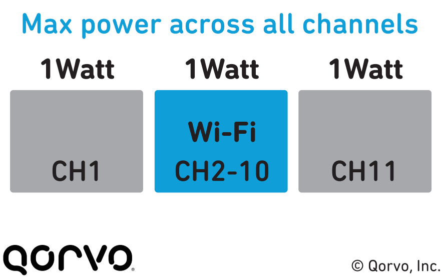
Of these conditions, low TCF and high out-of-band rejection are the most difficult parameters to achieve.

As Wi-Fi units pack high-levels of integration into smaller, sleeker form factors, performance over temperature and high power is a growing concern. The two filter technologies that meet this need are FBAR and BAW as they achieve the form factor and required performance criteria. But, BAW out performs FBAR in power handling, temperature drift (low TCF), spurious suppression and ruggedness.

Temperature performance and out-of-band rejection become even more important when the filter is embedded inside an integrated front-end module (FEM), as this causes increases in operating temperatures. BAW filter technology is the best choice to meet these high operating temperature shifts. Thus, meeting the difficult high out-of-band rejection.

Let's use channel 1, with a 20 MHz bandwidth, as an example. At the channel's lower corner frequency of 2402 MHz, the power density is approximately 17 dBm/MHz. At 12 MHz below this point (2390 MHz), the spectral regrowth needs to be lower than -41.25 dBm/MHz to meet FCC regulations. To meet this requirement, the filter's frequency response profile needs to have a steep roll-off and out-of-band rejection (30 dB as discussed above). BAW filters have these characteristics and are the best candidates for improving bandedge power in a Wi-Fi system. Using a BAW edgeBoost filter allows you to maximize linear power output across the entire Wi-Fi band and provide flat power across all channels within the full band (see Figure 4).

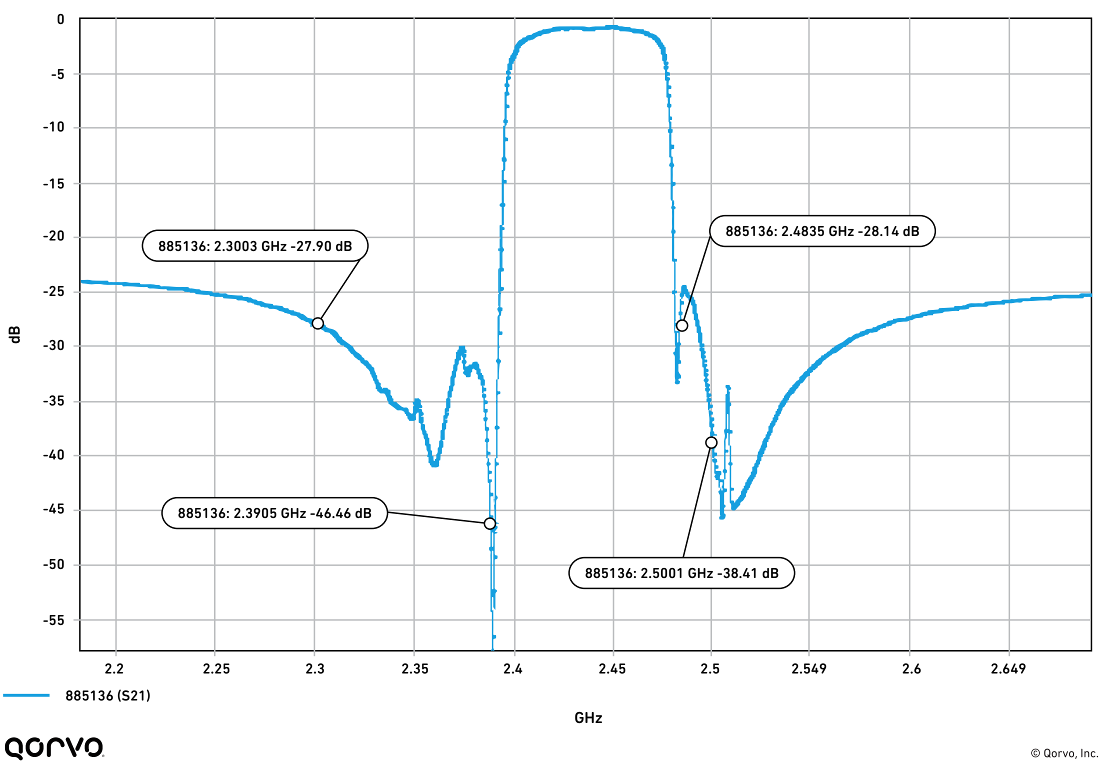
Figure 4: Flat power across all usable Wi-Fi channels can be achieved by using a Qorvo edgeBoost BAW filter.



How does the Qorvo BAW filter improve linear power and help pass the FCC bandedge test?

As discussed, the 2.4 GHz Wi-Fi band has a total of 14 available 20 MHz channels; in the U.S., FCC restrictions allow only 11 of those channels to be used, and only three of the channels are non-overlapping. Below (Figure 5) is a typical BAW filter frequency response showing the pass band, typical insertion loss, and rejection at the FCC restricted band.

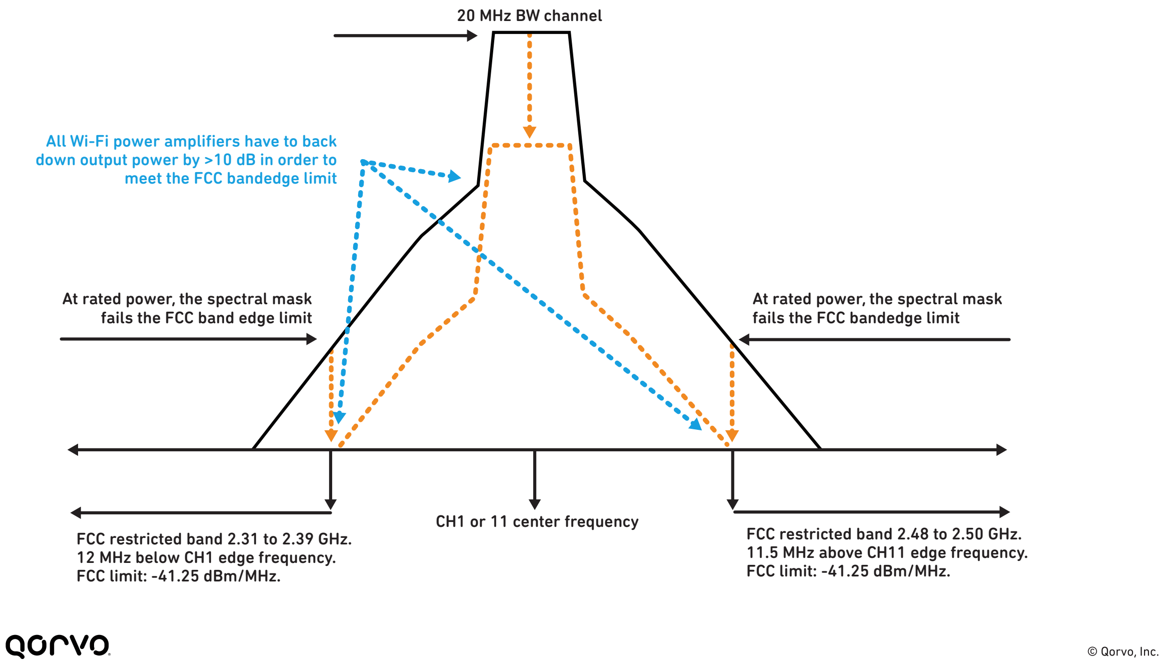
Figure 5: Typical frequency response for edgeBoost BAW.



Figures 6-8 show the bandedge failure response and illustrate how Qorvo BAW filters help recover linear power while rejecting unwanted transmissions in the FCC restricted bands. The figures show the effect on a 20 MHz signal in channels 1 and 11, which are severely impacted non-overlapping channels within the passband.

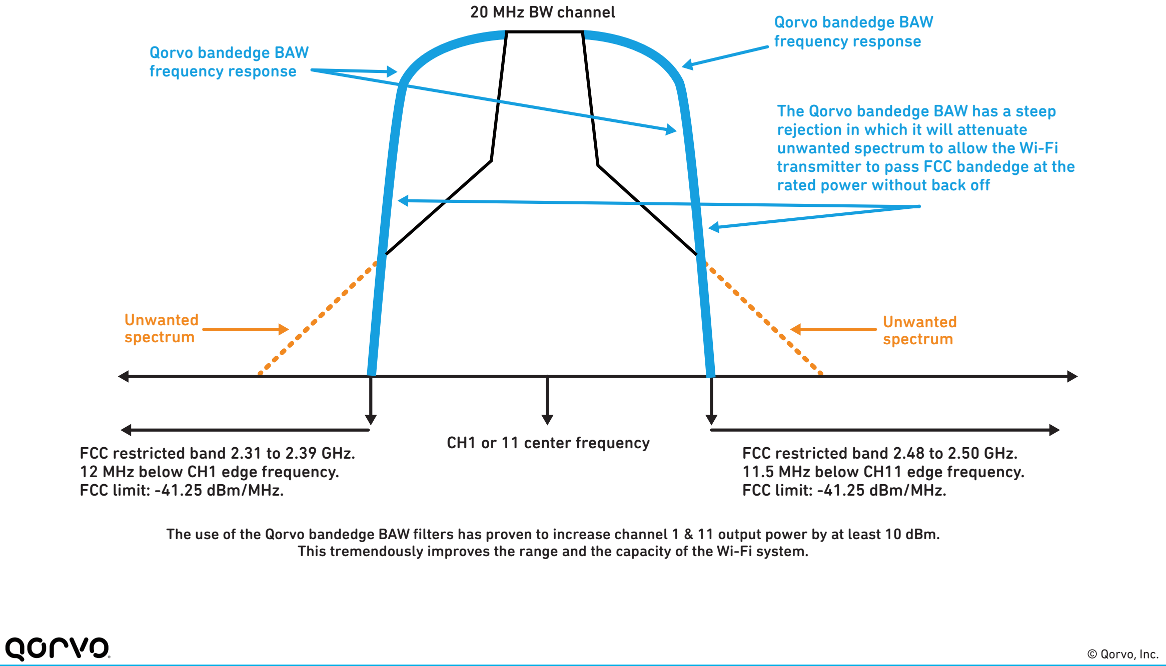
Figure 6 illustrates the FCC bandedge issue for a Wi-Fi transmitter set to channel 1 and 11, which are two of the three non-overlapping channels in the 2.4-2.5 GHz band. The FCC allows maximum output power of 30 dBm, but since the restricted band is only 12 MHz below the edge of channel 1 and 11.5 MHz above the edge of channel 11, the spectral mask violates the FCC limit for the restricted band and therefore will not gain regulatory approval.

Figure 6: Without BAW filter, power back-off on channel 1 and 11 is required to meet FCC bandedge limits.



As shown in Figure 7, the use of the Qorvo edgeBoost filters has been shown to increase Channel 1 and 11 output power by at least 10 dB by rejecting the unwanted spectrum.

Figure 7: With Qorvo BAW filter: Steep frequency response profile at the bandedge helps to recover linear power on channel 1 and 11.

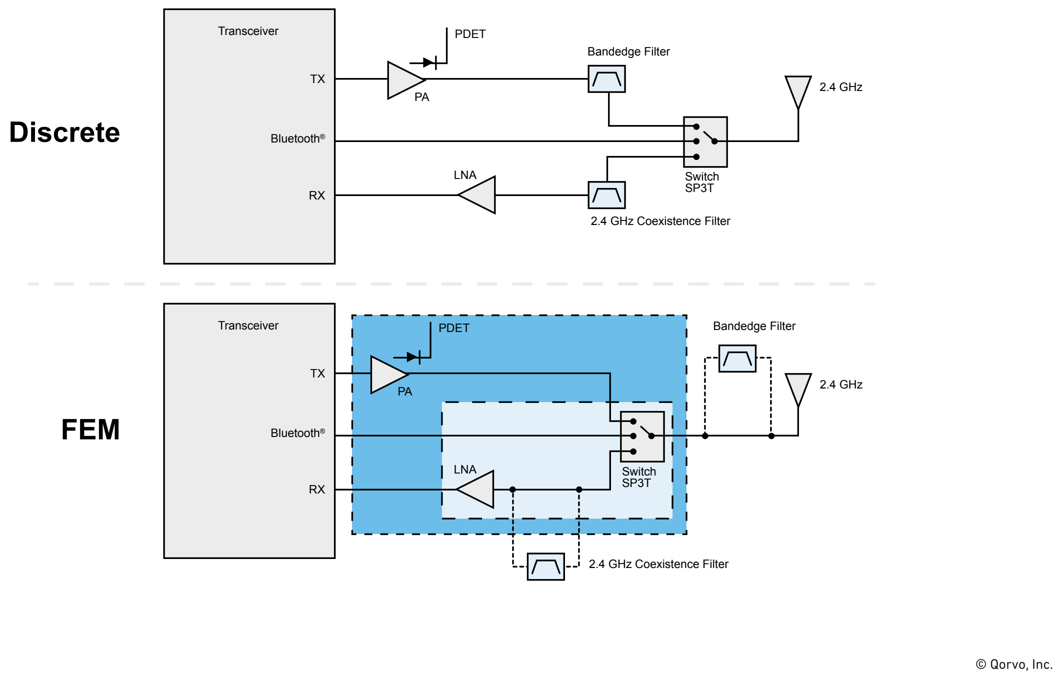


As shown in above Figures 6-7, the BAW filter greatly improves linear output power on edge channels 1 and 11. Now let's explore where best to place the filter in the system.

BAW Filter Placement and Trade-Offs in a System

The ideal placement for the bandedge BAW filter is between the PA (power amplifier) and switch on the transmit side. This configuration takes full advantage of the BAW OOB rejection and reduces distortion levels of the system. But, this placement may not always be possible when using a FEM that has a PA, switch, etc. If a FEM is used, the BAW filter should be placed at the common antenna port.

Figure 8: edgeBoost and coexBoost filter placement in application.



While the BAW placement improves OOB rejection, it also adds to RF path insertion loss, which needs to be considered. Thus, it may degrade the receive noise figure, which contributes to lower receiver sensitivity, and reduced linear power on the transmit side, by the amount of the insertion loss. When placing your filter, make certain you compensate for any degradation in performance.

Conclusion

Qorvo is the only supplier of Wi-Fi edgeBoost BAW filters at 2.4 GHz. Qorvo edgeBoost filters improve quality of service for Wi-Fi systems by allowing systems to maintain maximum power, range and capacity for all channels in the 2.4 to 2.5 GHz Wi-Fi band. As shown in below Table 3 and 4, Qorvo offers a family of edgeBoost (BAW bandedge) and coexBoost™ (coexistence) filter for LTE to Wi-Fi.

The list of products is below, for reference:

Table 3: Qorvo edgeBoost for 2.4 GHz.

Part Number	Function	Wi-Fi Channels	Insertion Loss (dB)	Attenuation 2370-2390 MHz (dB)	Attenuation 2483.5-2500 MHz (dB)	Attenuation 2500-2520 MHz (dB)	Size (mm)
885136	2.4 GHz FCC Bandedge	1-11	0.8	31	24	25	1.1x0.9
885070	2.4 GHz FCC Bandedge	1-11	0.8	19	24	38	1.7x1.3
885135	2.4 GHz EU Bandedge	1-12	0.8	19	20	33	1.7x1.3

Table 4: Qorvo coexBoost Wi-Fi/LTE.

Part Number	Function	Wi-Fi Channels	Insertion Loss (dB)	Attenuation 2300 - 2370 MHz (dB)	Attenuation 2370 - 2375 MHz (dB)	Attenuation 2375 - 2380 MHz (dB)	Attenuation 2500 - 2505 MHz (dB)	Attenuation 2505 - 2570 MHz (dB)	Size (mm)
QPQ1907	2.4 GHz Wi-Fi/BT to LTE Coexist	1-13	1.0	41	45	42	36	61	1.4 x 1.2
885128	2.4 GHz Wi-Fi/BT to LTE Coexist	1-13	1.1	39	42	34	41	55	1.1 x 0.9
885062	2.4 GHz Wi-Fi/BT to LTE Coexist	1-13	1.5	53	55	45	41	55	1.4 x 1.2
885071	2.4 GHz Wi-Fi/BT to LTE Coexist	1-13	1.5	53	49	30	57	54	1.4 x 1.2

For more information about Qorvo's BAW filters, please visit the below link: **https://www.qorvo.com/innovation/technology/baw**

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Jaidev has 12+ years of RF and system experience that relate to multiple wireless systems such as Wi-Fi, IoT, LTE, etc. Jaidev manages Qorvo's Wi-Fi application team within the wireless communication business unit, that supports customers around the world.

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