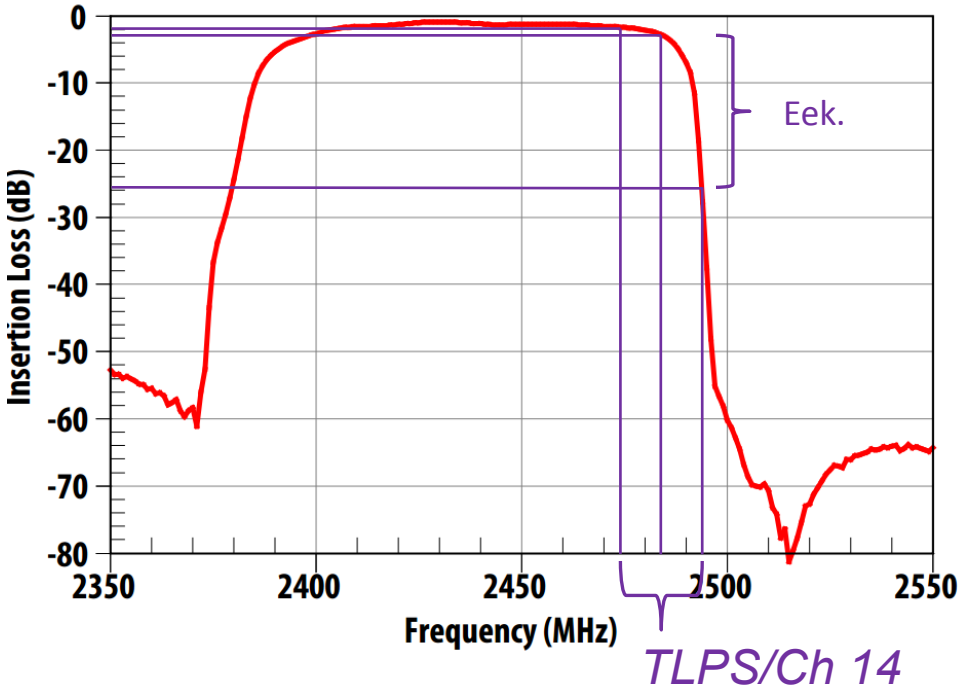
Would TLPS Even Work on Your Phone?

Filtering Poses a Major Threat to TLPS Usability



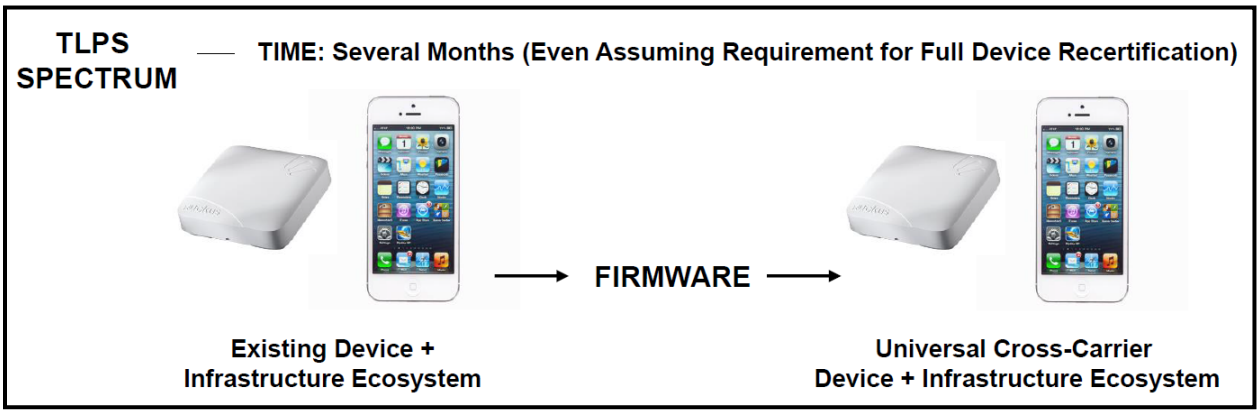
This graph illustrates the impact that the filters inside many mobile devices have on Channel 14 signals: dramatic degradation. These filters are tiny devices that transform radio signals by allowing certain frequencies through but suppressing others. The y axis measures the attenuation, or suppression, of the signal. A more negative figure in decibels corresponds to a more attenuated signal. The x axis measures the frequency of the signal. At the high-frequency edge of Channel 14, the attenuation would be approximately 25 decibels -- a reduction in signal strength of more than 300 times.

Source: Avago Technologies ACFF-1024 data sheet (p. 3), Kerrisdale analysis
Note: purple lines and label added to Avago graph to highlight the level of typical insertion loss at the edges and center of a hypothetical 802.11n Channel 14 (2474-2494 MHz).

One of the key purported advantages of Globalstar's (NYSEMKT:GSAT) Terrestrial Low Power Service (TLPS) is the existence of a large number of 2.4GHz Wi-Fi devices that, according to Globalstar, have the technical ability to transmit on its channel but are prevented from doing so via firmware. As Globalstar wrote in its initial petition to the FCC (p. 3),

> 802.11 compliant hardware is already capable of utilizing 802.11 Channel 14 with a device firmware modification. This means that TLPS will benefit from a substantial existing ecosystem, which can be utilized almost immediately.

Though "[m]ost if not all TLPS access points," in Globalstar's words (p. 42, footnote 105), "will be newly manufactured equipment" under the control of a hypothetical "network operating system" that will supposedly prevent interference to the company's satellite customers, no one envisions TLPS-specific user devices. Instead, the dream put forth in, for example, Globalstar's October 9 attempt to rebut our arguments, is that it will only take "several months" following the finalization of the TLPS rule to enable the service in popular devices like the iPhone.



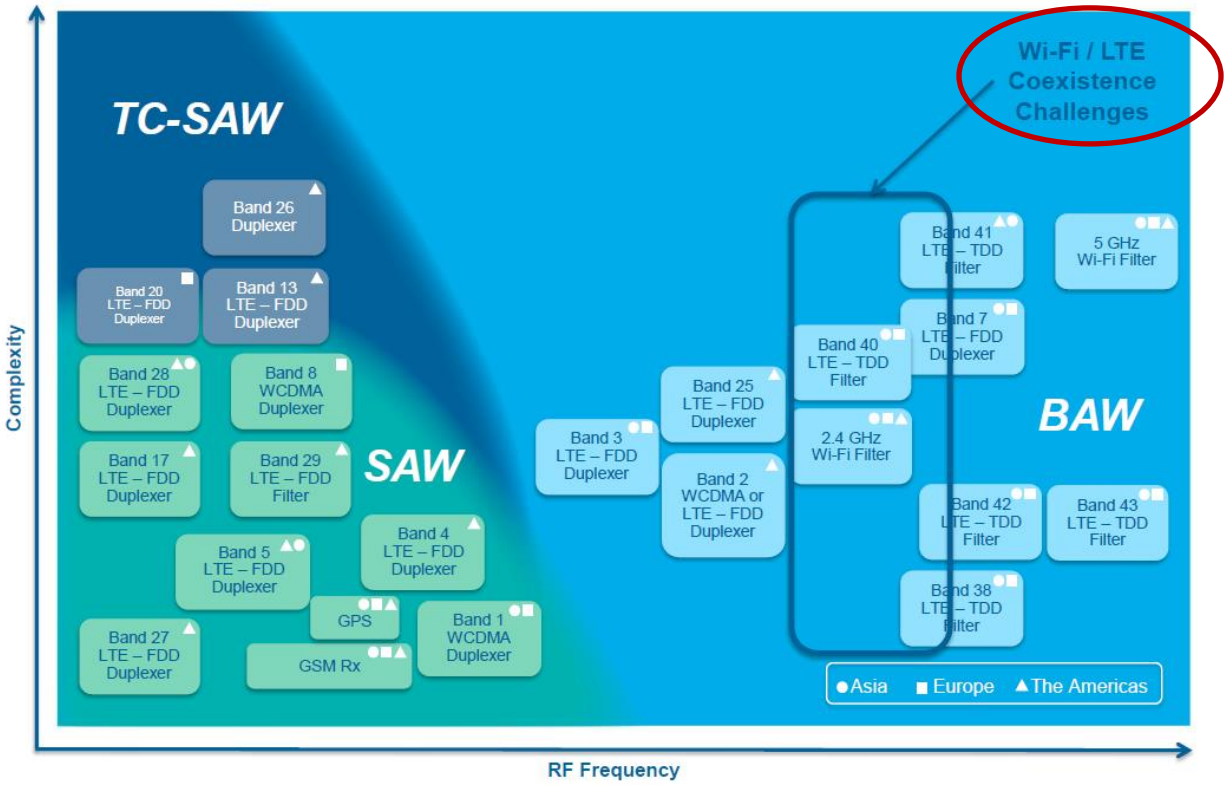
Source: "Globalstar Value Proposition," October 9, 2014, slide 30

Globalstar has neither the means nor the right to create, let alone disseminate, these firmware updates, which would be specific to individual manufacturers and device models. The manufacturers, likely in collaboration with chipset vendors, would have to choose to undertake this work, for no apparent reward. Though this practical hurdle to deployment is indeed serious, here we focus on a different concern: **Wi-Fi/LTE coexistence filters**. Assume that an iPhone 6, Samsung Galaxy S5, or other popular user device did indeed receive a firmware update that freed it to transmit on Channel 14. *The problem is that hardware filters inside many of these devices would severely impair the resulting signals.* In some cases, like the Avago filter shown above, a filter would attenuate the signal *by a factor of >200x* before it even left the phone. Needless to say, this would degrade the performance of TLPS, especially relative to Globalstar's ludicrous hype, and in some scenarios could render it unusable. The entire point of these filters is to suppress transmissions that lie outside of their "passbands," meaning the range of frequencies that pass through the filter largely unscathed; since much of Channel 14 does lie outside of their passbands, it's no surprise that the results could be disastrous.

Why has Globalstar never discussed (or perhaps even noticed) this problem? One likely reason is that it has never actually tested TLPS using real user devices, at least according to its experimental-license applications to the FCC, which have only mentioned access points, not user devices like phones or tablets. In its recent *ex parte* letter responding to some of our concerns, Globalstar did not even claim to have tested user devices, speaking only of "access point transmissions" (p. 2). Without even attempting to connect real devices to TLPS APs - perhaps because it has been unable to properly modify third-party firmware for which it lacks the source code - Globalstar would be unlikely to come across this problem. But it would obviously loom large in the mind of any potential partner. After all, why pay billions for TLPS if the most popular mobile devices in the world can barely use it?

Nor is there any easy fix. While we believe that similar coexistence filters would also impair Channel 14 transmissions from many *access points* - indeed, even on the Ruckus access points that Globalstar purportedly used for some of its testing - the impact is potentially mitigated by Globalstar's intention to deploy custom APs (albeit at higher cost). For user devices, however, the story is different. The filters used to prevent Wi-Fi signals from interfering with nearby LTE bands are already high-performance, state-of-the-art devices, yet it's already difficult for them to achieve the required signal rejection given how narrow of a window they have to work with. (A very informative presentation submitted to the FCC by a filter industry group characterized the 2.4GHZ Wi-Fi band as "very hard" to handle given the tight spacing between it and the LTE bands on either side.) Channel 14 effectively *is* the guard band between the 2.4GHz ISM band used by Wi-Fi and Bluetooth and the neighboring higher-frequency LTE bands, like the Sprint-dominated Band 41 (2496-2690 MHz) - just as Globalstar's 1.6GHz uplink spectrum acts as a guard band between GPS and other navigation frequencies and LightSquared's uplink band. In both cases, Globalstar's bands have highly unattractive neighbors from the perspective of a terrestrial deployment - a logical outcome since they were never originally intended to serve that purpose. With so many shortcomings and technical challenges, TLPS has no hope of warranting the $3 billion valuation that the equity market has given it. Globalstar remains dramatically overvalued.

I. What Is Wi-Fi/LTE Coexistence?



Source: TriQuint Investor & Analyst Day presentation, October 31, 2013, slide 49

The Japanese electronics manufacturer TDK provided a good summary of Wi-Fi/LTE coexistence problems in a recent press release announcing its new "high-performance WLAN-Bluetooth filter for smartphones":

> RF spectrum is a limited resource and with the continuously growing number of communication services it is becoming ever more densely populated. In particular, the WLAN and Bluetooth band between 2400 MHz and 2483 MHz is separated by just ≤20 MHz from the new band 7, 40 and 41 that are used for LTE cellular service. Thanks to the new filter's excellent insertion loss and high out-of-band selectivity, the B8831 is able to prevent the signals in the adjacent WLAN/Bluetooth and highband cellular bands from interfering with each other.

But TDK is far from the first entrant into this market. For years, Avago (NASDAQ:AVGO) and TriQuint (NASDAQ:TQNT), which is on the eve of combining with RF Micro Devices (NASDAQ:RFMD) to form a new firm called Qorvo, have dominated the world of high-performance RF filters, including Wi-Fi coexistence filters - and their stocks have delivered excellent returns along the way. As early as its February 2011 investor day, TriQuint flagged Wi-Fi coexistence as a key opportunity:

> And the final piece, 4G wireless LAN coexistence. Sprint came out with basically 4G WiMAX, but then wireless LAN capability in terms of personal hot spots, and then was also looking to do it in phones. And what we're seeing is any type of application, whether it be a mobile application or a fixed network application, that puts those two together creates opportunity because the frequency spectrum is so close to each other, you need very, very tight filtering requirements now at very high frequencies to be able to handle that. And that's created an opportunity with our BAW filtering technology and leveraged a lot of our growth here this past year. (*Source: Bloomberg transcript of TriQuint 2011 Investor Day, February 23, 2011*)

These comments echoed those of other organizations. In March 2010, the Bluetooth Special Interest Group released *Filter Recommendations for Coexistence with LTE and WiMAX*, noting that "based on information from the filter manufacturers shown in Appendix B: Available Filter Performance, a reasonable bandwidth of such a guard band [between the 2.4GHz band used by Wi-Fi and Bluetooth and neighboring LTE bands] is 20 MHz," though it noted that "some WiMAX deployments" - now undergoing conversion to LTE - "start at 2496 MHz which reduces the guard band to 16 MHz" (p. 9). As this language shows, filter-makers disregarded the barely used, vestigial Channel 14 (centered on 2484 MHz), characterizing it as part of the guard band and making no effort to preserve its functionality. In December 2011, the global telecom consortium 3GPP, which develops the rules for LTE, released a technical report on "in-device coexistence," drawing in part on a prior study by Motorola that assumed the use of a high-performance, *Channel 14-impairing* Avago ACPF-7024 filter. IWPC, a telecom industry group, published a study in April 2013 examining *RF Front-End Architectures for 2.3-2.7 GHz 4G Global Roaming Devices;* the study concluded in part that "LTE bands can be adequately

protected from an in-device Wi-Fi radio by a single post-[power amplifier] filter on the Wi-Fi device with 40-45 dB rejection" (p. 85). 40-45 dB equates to a factor of 10,000x to ~32,000x signal attenuation - an enormous degree of "rejection." Given that Channel 14 lies right between the Wi-Fi band that these filters are designed to let through and the LTE bands they are designed to protect with massive amounts of rejection, Channel 14 is firmly and unavoidably in the cross-hairs.

Though different device models contain different filters, it's clear that the high-performance filters that do the greatest damage to Channel 14 are widespread. For example, in 2013, TriQuint announced that its LTE/Wi-Fi coexistence filter was included in Broadcom's reference designs for 802.11ac mobile devices. In 2014, it announced yet more wins:

> TriQuint also launched a family of three high-performance filters to solve challenging Wi-Fi / LTE interference issues. Utilizing TriQuint's bulk acoustic wave (BAW) technology, these advanced filters enable customers to extend Wi-Fi ranges while meeting stringent spectrum regulations worldwide. TriQuint has already secured multiple design wins for these filters in Wi-Fi access points, home media gateways and automotive infotainment markets.

TriQuint specifically touted one of its new models, the 885070, as the "first BAW filter to provide guaranteed band-edge rejection in restricted FCC bands at 2390MHz & 2483.5MHz." In other words, this filter is guaranteed to wipe out the entire upper half of Channel 14.

Because filters are small (e.g. the ACPF is 1.6x2.0x0.95 millimeters) and sometimes unlabeled, "teardown" analyses in which engineers take apart new mobile devices to examine their components sometimes overlook them[1]. Nonetheless, semiconductor analysts have identified high-performance Wi-Fi coexistence filters in many popular devices. For example, in April Barclays identified an Avago "WLAN coexist FBAR" (a specific type of filter) in the Samsung Galaxy S5:

[1] Brean Capital's TriQuint analyst Mike Burton made this point in his October 29 piece on TriQuint, "So Much for Teardowns," writing, "As expected, Apple was the main revenue driver, with the big story being TQNT's filter business, as discrete filters are set to triple in 2014…Since the first iPhone 6/6+ teardowns appeared, investors have been concerned, and some of our competitors even went so far as to write that TQNT had lost content in the new iPhone 6, as there were no TQNT markings visible on any components. However, in light of TQNT's optimistic guidance, we assumed that either there was content we could not discern from the teardown, or there were multiple SKUs for each phone, or both. We now believe that there are multiple SKUs AND that TQNT has discrete, high-margin, filter content on the new iPhones."

Barclays | U.S. Semiconductors

Samsung Galaxy S5 Content

FIGURE 1
Samsung Galaxy S5 Semiconductor Content

Samsung SM-G900S (Korea)		
Supplier	**Initial Markings**	**Description**
AMS	Not identified yet	Gesture IC
Audience	ADNC ES704	Stand-alone Voice Processor
Avago	A7007	B7 PAM
Avago	ACPM-7617	MMMB 2G/Edge, 3G, LTE
Avago	+ACW	WLAN coexist FBAR
FCI (Silicon Motion)	FC8080	Terrestrial Digital Multimedia Broadcast RF Tuner & Demod
Invensense	MP65M	6-axis Gyro/Accelerometer
Lattice	LPIK9D	Low-power FPGA
Maxim	MAX77804K	System PSoC
Maxim	MAX77826	Likely Battery/Power
Maxim	Not identified yet	Biosensor - Pulse/Oxy IC
NXP	47803	NFC + Secure Element (Region specific)
Qualcomm	QFE1100	Envelope Tracking
Qualcomm	WTR1620	Receive Only
Qualcomm	WTR1625L	Transceiver
Qualcomm	MSM8974AC (under RAM)	Snapdragon 801 (BB/AP SoC)
Qualcomm	WCD9320	Audio Codec
Qualcomm	PMC8974	BB/AP Power Management
RFMD	RF1119	Antenna Control Solution
Samsung	K3QF2F20DA	Likely 2GB RAM
Samsung	CML2569U	Likely 16/32GB NAND Flash
Silicon Image	8240B0	MHL Transmitter
STMicro	32A M409	Unknown
STMicro	32HUBI	Sensor Hub
Synaptics	S5100A0	Touch Controller
Synaptics	Not identified yet	Swipe Touch IC
Unknown	C1N78B	Unknown
Unknown (likely Murata)	SWCP	Antenna Switch Module
Unknown (likely Semco)	4452M3	WLAN Module (BCM4354 inside)

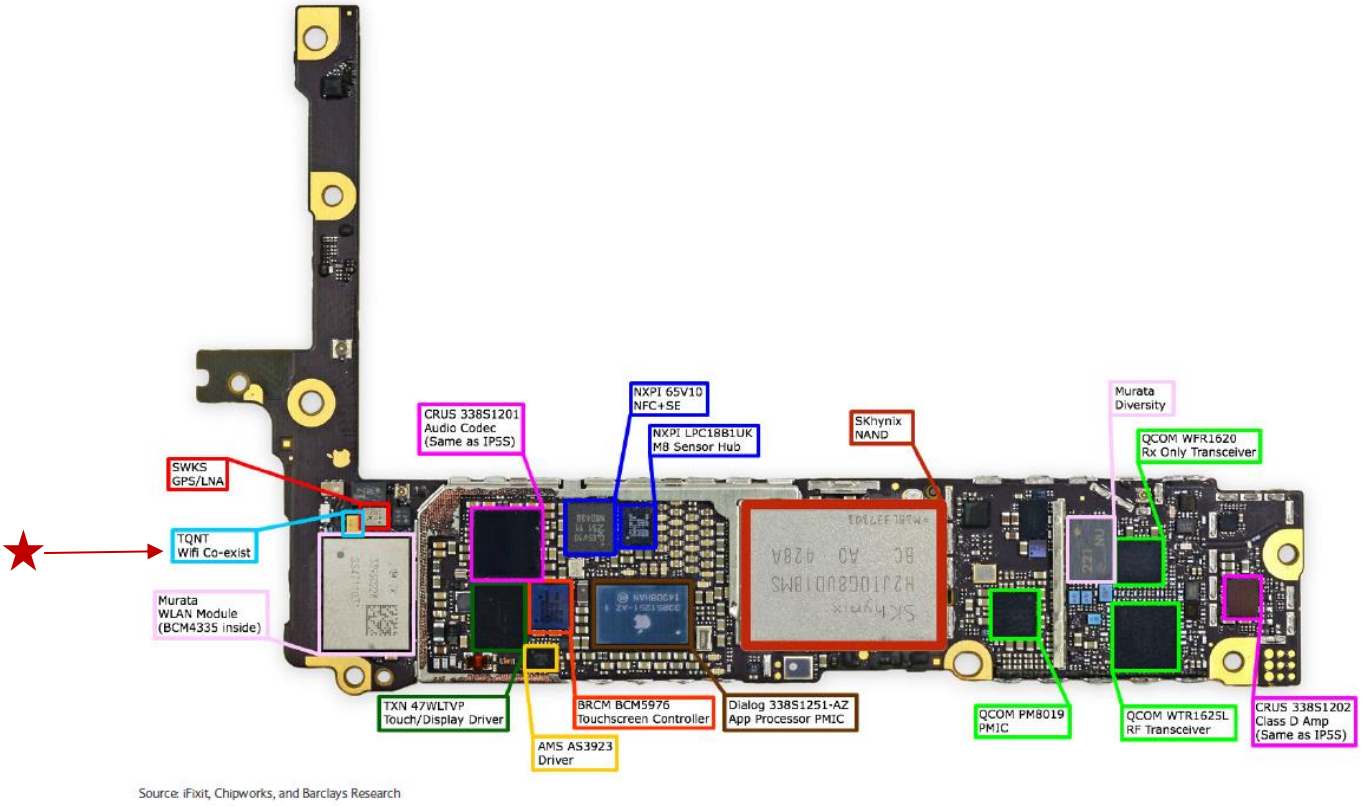
Source: Chipworks.com, Barclays Research Estimates

Source: Barclays equity research, "U.S. Semiconductors: GS5 Teardown 2 – Another Teardown Provides Further Insight," April 1, 2014, p. 2

Note: red arrow and box added by Kerrisdale.

In September, Barclays also identified TriQuint "WLAN co-exist" filters in the US/Canada/Europe and China/Other versions of the iPhone 6, an increase over the iPhone 5S/5C, where it identified such filters in only a subset of models.

FIGURE 3
iPhone 6 Plus Circuit Board - Back



Source: iFixit, Chipworks, and Barclays Research

Source: Barclays equity research, "U.S. Semiconductors: iPhone 6 Teardowns – Preliminary Thoughts for Semis," September 19, 2014, p. 4

Note: red arrow and star at left added by Kerrisdale.

These much-scrutinized, best-selling devices are not unique in their reliance on strict filtering of the 2.4GHz Wi-Fi band. During TriQuint's April 2014 earnings call, its CEO noted that "the Wi-LAN business associated with co-existence filters, that's our fastest-growing product line right now." Not just user devices but access points now boast more selective filters. Aruba, for example, advertises "advanced cellular coexistence," while Ruckus notes that it too employs a "2.4 GHz ISM filter" (slide 11).

In short, Wi-Fi/LTE coexistence filters are pervasive in mobile devices as well as access points. They're needed in order to prevent Wi-Fi and LTE interfering with one another. Because Channel 14 is effectively unused, filter-makers have not attempted to protect it in their efforts to keep the 2.4GHz ISM band and neighboring LTE bands from harming one another. As a result, any device that contains such filters will perform poorly and unpredictably when set to Channel 14 - even if a firmware modification allows it. Depending on the filter in place, the impact could be drastic.

II. What Impact Do the Filters Have?

To estimate the impact of coexistence filtering on Channel 14, we have used data sheets from the filter vendors TriQuint and Avago, drawing on the performance graphs that they provide in order to zero in on the expected level of attenuation within the bounds of the channel. Since filter performance varies based on temperature and other factors - and even varies from one tiny unit to the next based on small fluctuations in the manufacturing process - these are only estimates. But they highlight yet another enormous practical headache for any TLPS deployment - one that, as usual, Globalstar has never publicly acknowledged.

Below we summarize our findings:

		*Insertion loss **in dB** at given frequency*			**Reduction in signal strength at 2494 MHz**
Manufacturer	*Part number*	2474 MHz	2484 MHz	2494 MHz	
TriQuint	885032	1.8	3.5	26.9	**491x**
TriQuint	885033	1.4	2.4	16.6	**45x**
TriQuint	885017	1.6	3.8	24.5	**284x**
TriQuint	885062	1.7	2.3	12.5	**18x**
Avago	ACFF-1024	1.9	2.8	25.6	**362x**
Avago	ACPF-7024	1.7	2.5	15.0	**32x**
TDK	B9604	2.4	3.9	25.3	**335x**

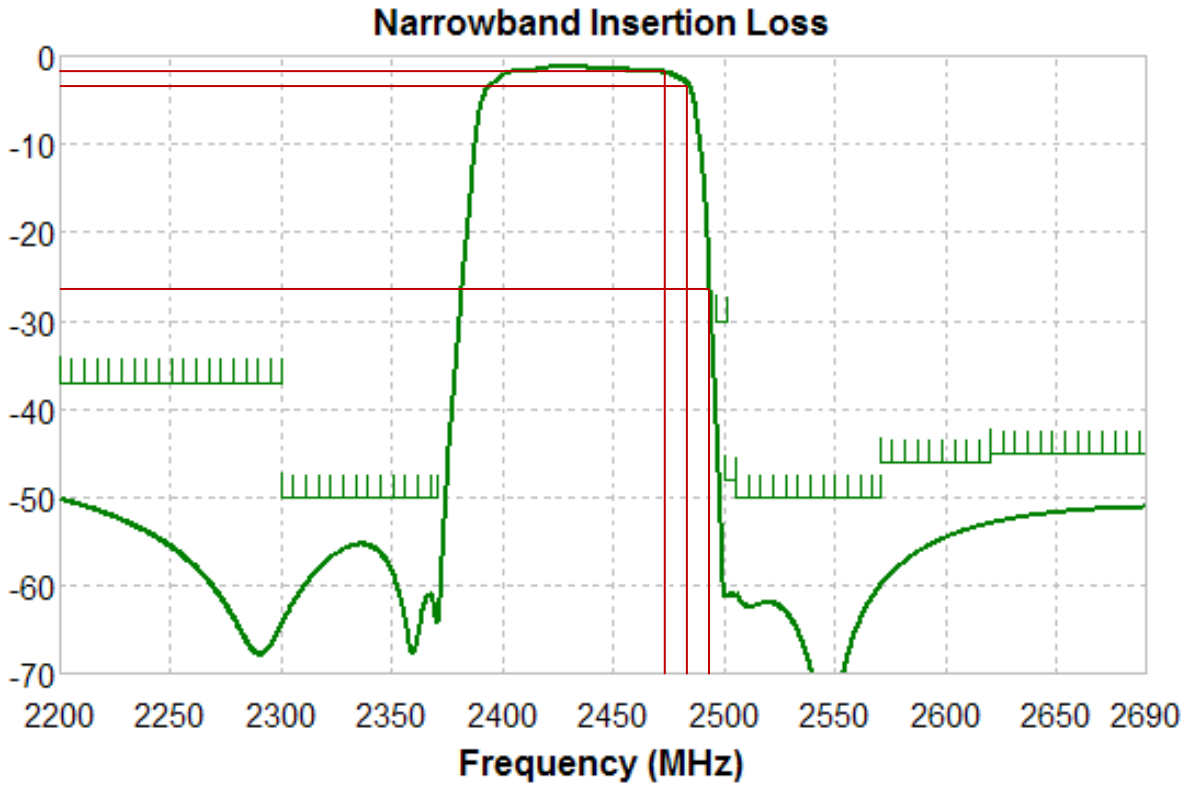
Source: vendor data sheets, Kerrisdale analysis

"Insertion loss" simply refers to the reduction in signal strength at a given frequency caused by the filter. (In some sources, the term "insertion loss" is used more narrowly to refer to the undesirable but unavoidable reduction in signal strength experienced in the passband only, while the reduction in out-of-band emissions is called "rejection.") Since measurements in decibels can be unintuitive to those without RF experience, we also express the insertion loss as a straightforward ratio.

In most cases, at the center of Channel 14, the attenuation is ~3 dB, equivalent to a *halving* in signal strength. By the edge of the channel at 2494 MHz, however, the attenuation in all cases becomes extremely severe, ranging from ~12.5 dB (18x reduction in signal strength) to ~26.9 dB (491x reduction in signal strength). The effects of attenuating some of the subcarriers within the channel by large amounts and others by less are difficult to predict without conducting extensive real-world tests, but at a minimum these reductions in signal strength would greatly limit propagation - ironic given Globalstar's insistence that TLPS would boast superior range over conventional Wi-Fi.

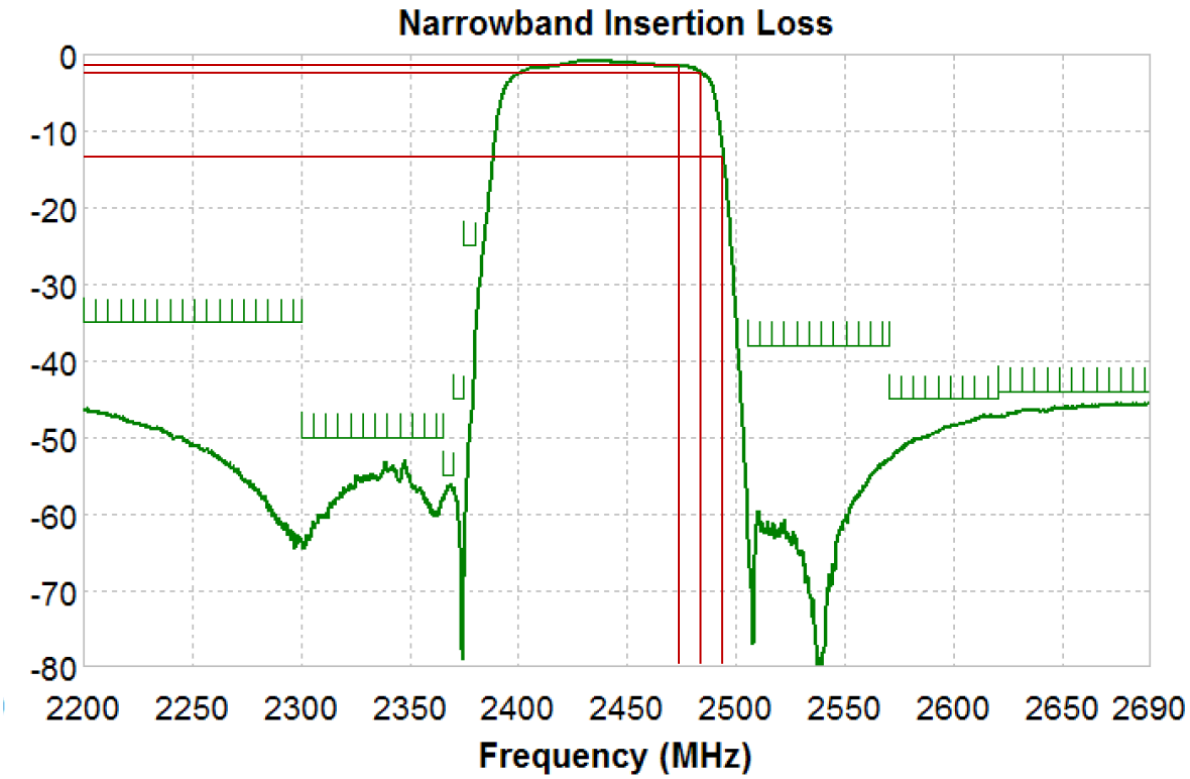
Below we show the performance graphs for each device, highlighting the relevant zone for Channel 14. (The ACFF-1024 was already illustrated on the first page.)

TriQuint 885032



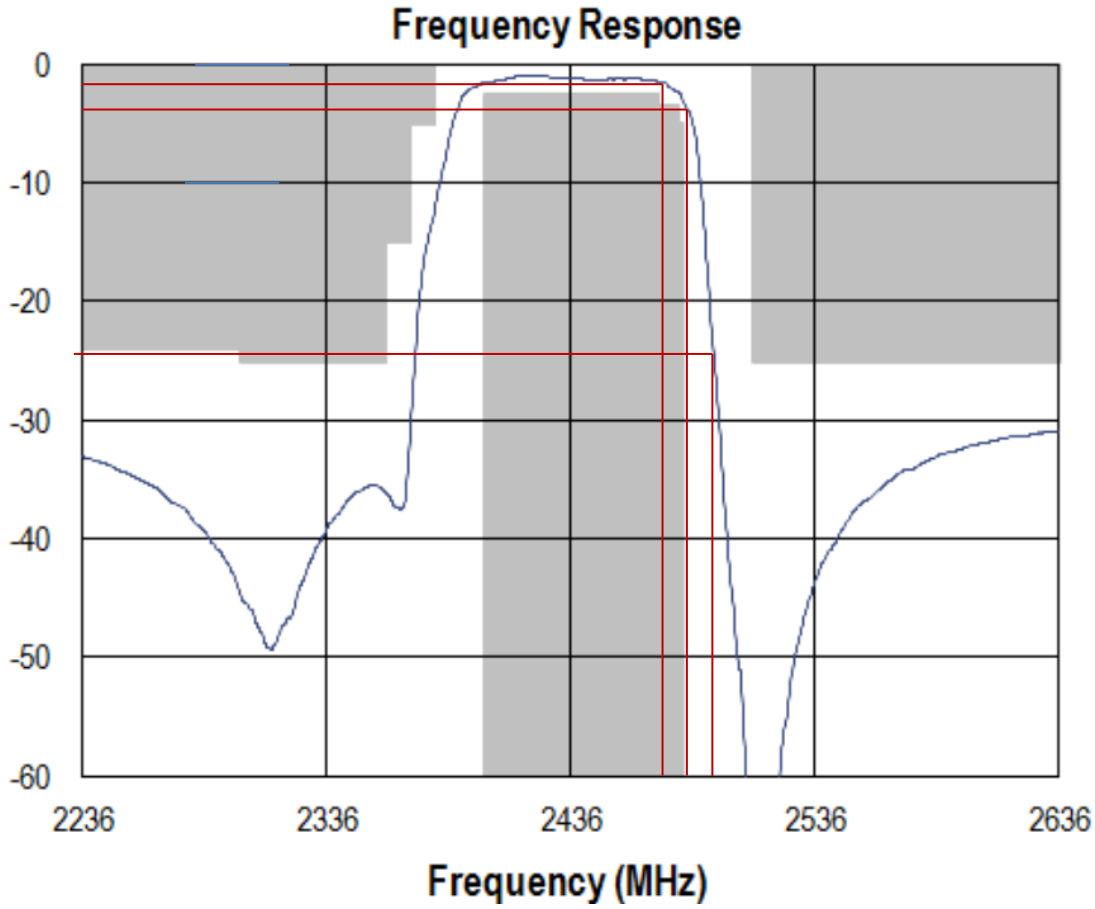
Source: TriQuint, Kerrisdale analysis

TriQuint 885033



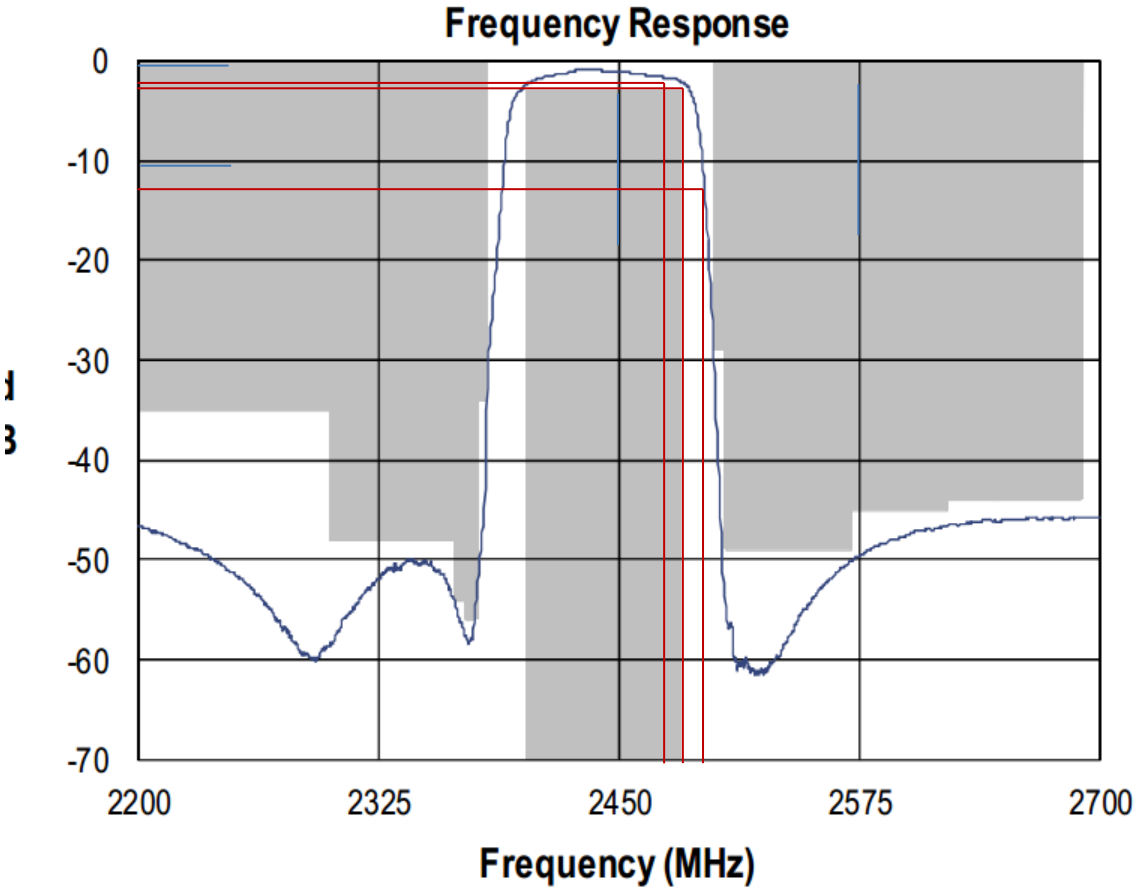
Source: TriQuint, Kerrisdale analysis

TriQuint 885017



Source: TriQuint, Kerrisdale analysis

TriQuint 885062



Source: TriQuint, Kerrisdale analysis

Avago ACPF-7024

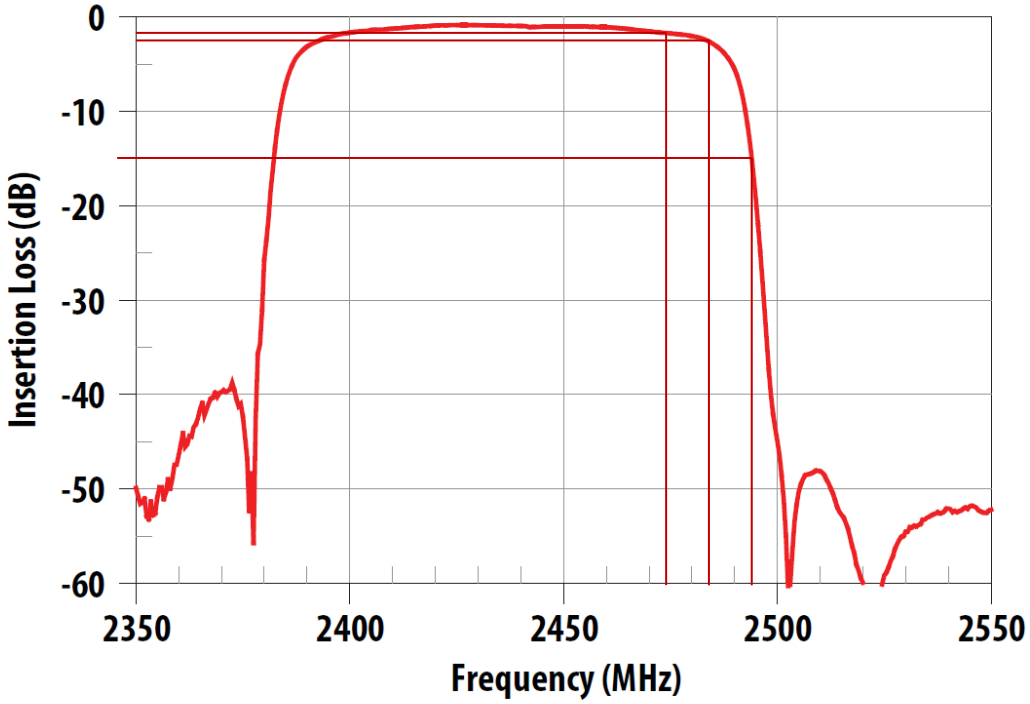
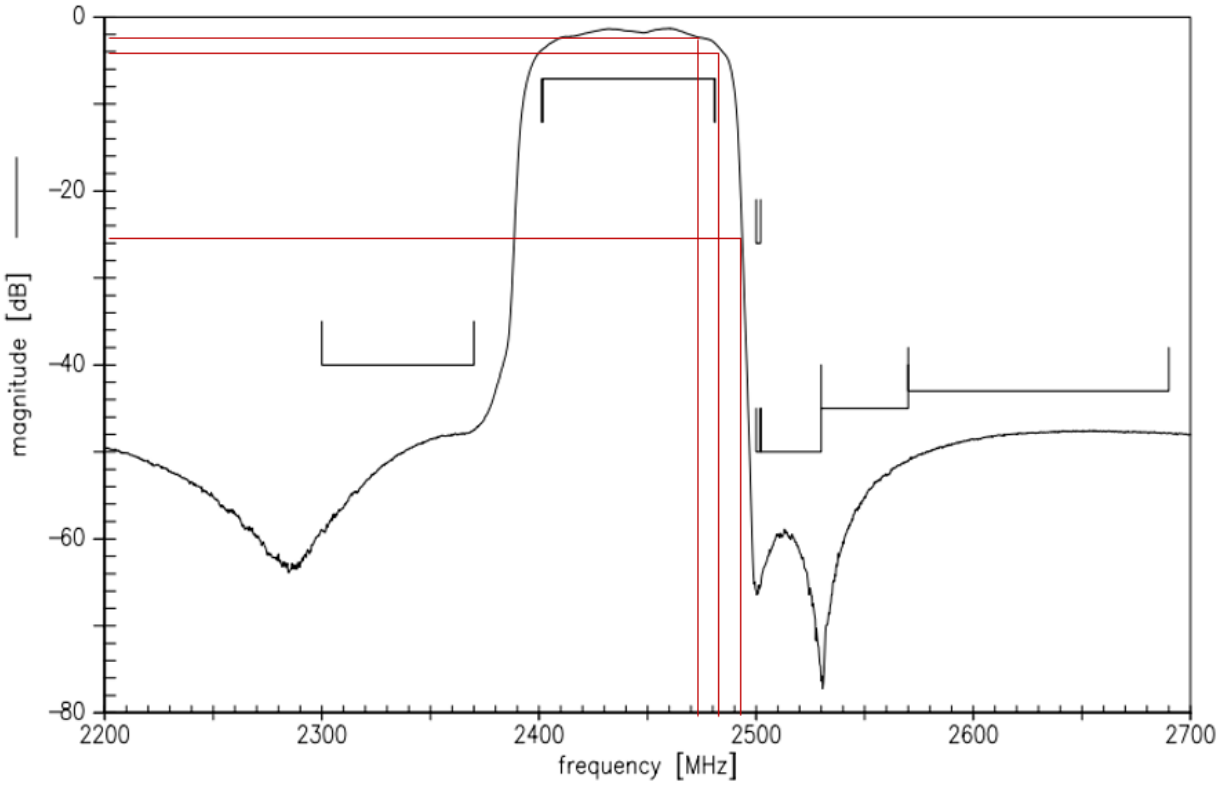


Figure 3. Attenuation, 2350 – 2550 MHz

Source: Avago, Kerrisdale analysis

TDK EPCOS B9604



Source: TDK, Kerrisdale analysis

III. Conclusion

TLPS is a veritable onion of badness - the more one peels it, the more flaws are revealed. Wi-Fi/LTE coexistence filtering is a major threat to its ultimately usability, let alone commercial viability, especially for mobile devices released over the last several years. Globalstar's failure to conduct real-world testing with actual user devices has left it open to exactly this sort of problem. Equity investors may be inclined to ignore such concrete technological issues in favor of buying into a puffed-up narrative, but no rational business would.

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