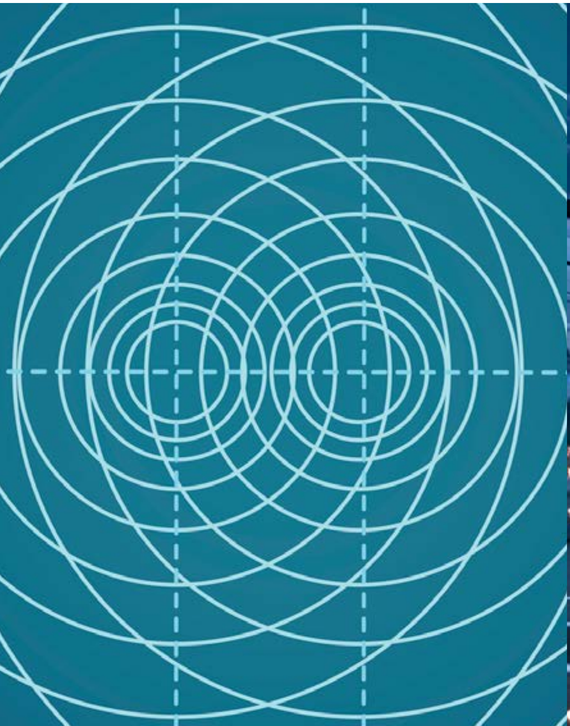
Cookbook for Filter Design

Ensuring 5G C-band interference mitigation for aircraft radar altimeter receivers

How Spectrum Control can help design special filters for altimeters and aircraft


C Band spectrum landscape


What is driving the need

Radar altimeter filter solutions


Special filter design

Introduction – Understanding how 5G networks affect aircraft

Dear Reader,

Radar altimeters are deployed on tens of thousands of commercial and general aviation aircrafts and helicopters worldwide. For decades, these devices have helped pilots accurately measure the altitude of their aircrafts' position to the ground so they can successfully maneuver and land. It's a critical tool for pilots during low-visibility weather conditions.

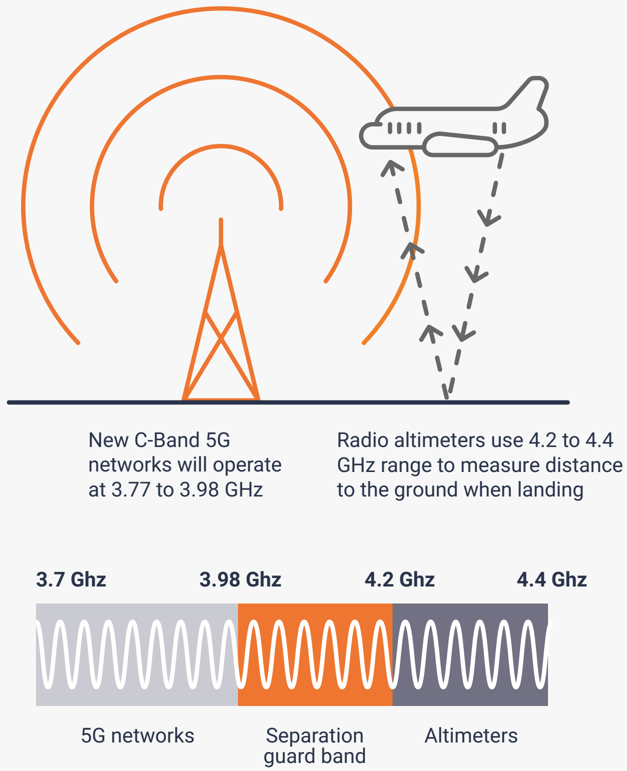
There are four types of altimeters, but the one that is cause for concern is the radar altimeter. These altimeters fly on most commercial airlines and the military relies on altimeters to enable aircraft to fly low to the ground to avoid detection by anti-aircraft guns or air missiles. Radar altimeters provide essential altitude data to flight crews and on-board systems during instrument-based approaches and landings.

Globally governments are freeing up the C-band spectrum to speed up the deployment of 5G services worldwide. The aviation industry and regulators are concerned these new re-licensed 5G upgrades will cause interference to radio altimeters operating in the radio frequency band of 4.2 to 4.4 GHz, which are in close proximity to the frequency of the 5G signal, and can cause an unmodified radar altimeter to be blinded.

So, what does 5G have to do with this?

One of the frequency ranges recently allocated to 5G is in the C Band, 3.7 to 3.98 GHz range. C Band is typically known as 4 to 8 GHz, but this is called C Band for 5G. This frequency has become very desirable to wireless carriers because it provides the ability to push lots of data over long distances. You not only get fast speeds due to wider bandwidths, but the frequencies are low enough that the signal can propagate further than higher frequencies. Radar altimeters typically operate in the 4.2 to 4.4 GHz bands, which is quite close to that previously mentioned 5G frequency range. 5G cell sites will be transmitting hundreds of watts of power, so there is a concern this aggregate power will cause interference with radar altimeters. Testing has shown that potential problems can range from inaccuracy to outright instrument failure.

Why airlines are worried about interference issues with 5G



Introduction – Understanding how 5G networks affect aircraft

Did you Know?

The main C-band frequencies have been used for satellite TV since the 1970s.

C-band satellite reception requires “big, ugly dishes” up to 10 feet in diameter, they have been generally replaced by more flexible systems with smaller dishes on the Ku band, such as DISH and DIRECTV. C-band is currently used for the “satellite downlink” for broadcast television distribution.

With more advanced methods of digital encoding than they had in the 1970s, the satellite companies can now “repack” their broadcasts into the upper portion of the C-band, leaving the lower portion available for cellular companies to use.

What is the industry doing?

Federal Aviation Administration (FAA) has released a bulletin advising radar altimeter and aircraft manufacturers of the possible interference. They have advised pilots to take precautions and prepare for degradation of their altimeter readings.

How do we solve the problem with altimeters giving inaccurate readings or simply failing to operate at all?

We rely heavily on aviation for everything, from going on vacation to fighting wildfires to commercial ventures. Spectrum Control is developing workable filter solutions to tackle this serious technical issue. To dive deeper into how Spectrum Control filter technology can help prevent 5G affecting aircraft avionics, please reach out to me.

David J Swift
Global Director of Telecom Sales, Spectrum Control

Where does Spectrum Control, 5G, and aviation meet?

Spectrum Control has more than 60 years of wireless device/system design, development, and innovation. Our deep heritage was built through several business units, which now operate as one, to offer the most comprehensive RF filtering technologies for wireless and avionics systems used in commercial and military applications.

The increased use of wireless communications technology in various subsystems means mobile service providers, avionics/wireless systems manufacturers need knowledgeable, skilled engineers who are able to meet the latest wireless communications technology challenges.

As new elements and new technologies, such as Open RAN, 5G, and advanced 6G, are introduced into the RF ecosystem, Spectrum Control is uniquely positioned to assist in helping you evaluate the risks and potential concerns. We provide use-cases that maintain and enhance air-traffic safety and work harmoniously with 5G-and-beyond technologies.

This cookbook covers:

1. **Current C Band spectrum landscape** – Why reallocating some of the C Band spectrum to 5G cellular wireless could create a public safety issue.
2. **What is driving the need?** Learn about radar altimeters band susceptibility to both 5G fundamental and spurious emissions.
3. **Radar altimeter filter solutions can help ensure aircraft safety.** Spectrum Control offers high-reliability cavity filters for mitigating 5G C-band interference in avionics systems.
4. **How can we help you?** Spectrum Control can design and manufacture special RF filter solutions that address the 5G frequency problem with current altimeters.

Current C Band spectrum landscape

Why is it a public safety issue?

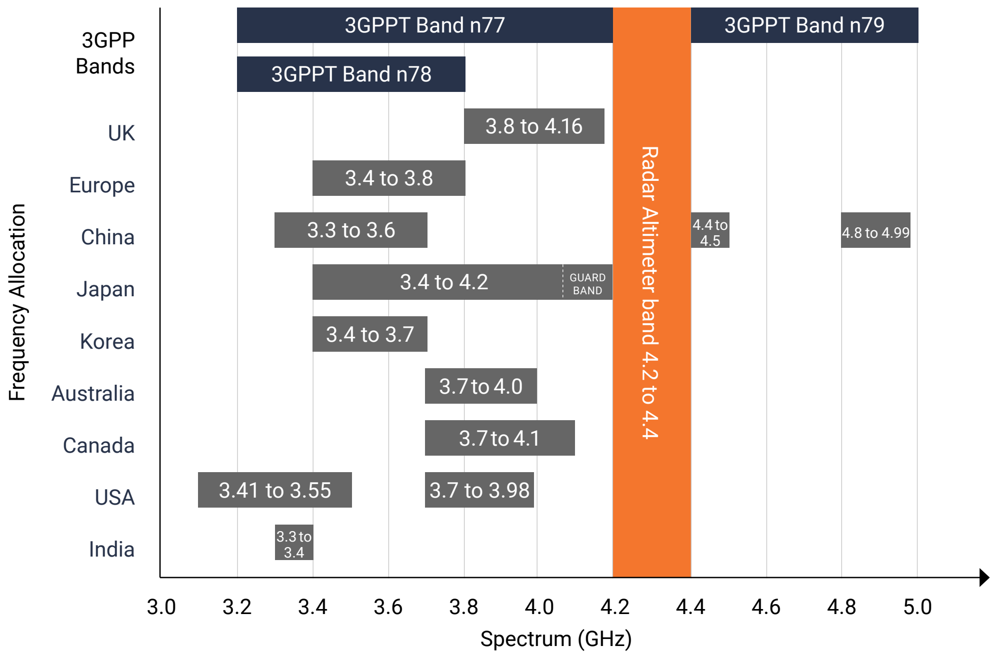
Until recently, the 3.7 to 3.98 GHz spectrum was used to communicate with low-powered satellites. So sharing this spectrum space with radar altimeters in the 4.2 to 4.4 GHz was not an issue because the low RF power provided space within the RF spectrum for radar altimeters to operate without crowded interference.

Radar altimeter design did not consider the problems that higher power 5G technology would create within the RF spectrum. So their RF front-end bandpass filters have been specified to roll off at 24 dB per octave below 4.2 GHz and above 4.4 GHz. Consequently, altimeters that are in use today have limited ability to reject fundamental emissions close to the 4.2 to 4.4 GHz band.

The chart shows the RF spectrum landscape of 5G networks that now are live in more than 50 countries, with more than 138 operators launching 5G services. They are trying to satisfy the increased demand for mobile data by expanding their spectrum usage into the upper N77 spectrum band. As you can see, the radar altimeter band is in the middle of 5G deployment in many countries. 5G transmitters using this spectrum will be deployed in numerous base stations and in large numbers of user equipment (UEs), both on the ground and in or around air traffic control areas. The density of base stations and UEs, and their proximity to aircraft, exacerbates conditions for potential interference with non upgraded radar altimeters. In other words, the more base stations and UEs, the more potential problems for aircrafts.

The avionics industry had done a lot of research on this issue. In response, it now has updated the required technical parameters for altimeters as part of the WRC-15 agenda. The Wireless Avionics Intra-Communications (WAIC), an aeroplane communications system, along with RTCA Inc., a non-profit aeronautics technical group, have outlined how the aviation industry is applying higher safety standards to 5G services that operate hundreds of megahertz from the radio altimeter band.

Spectrum Control can develop custom upgrades to deal with the spurious emissions from 5G commercial for Usage Category 1 (commercial air transport aircraft); Usage Category 3 (transport and general aviation helicopters) aircraft that may be impacted by interference between the radar altimeter receiver and a 3.5 GHz upper band 5G signal (C-Band) emitted from a base station co-located near an airport.



Did you Know?

The most important question with regards to 5G and aviation altimeters is how to enable co-existence between different technologies?

Currently, 5G live networks are using spectrum within the lower part of 3GPP Band N77 3.3 to 4.2 GHz (the 3.5 GHz band).

To increase network capacity mobile service providers are starting to use the upper part of this band as well as 3GPP Band N79 between 4.4 to 5 GHz and 3.8 to 4.1 GHz.

Aircraft altimeters licenced to use the 4.2 to 4.4 GHz band are impacted by 5G networks. RF filtering is key to ensuring safe functioning of altimeters used near 5G upper-band deployments.

What is driving the need?

Safeguarding radar-altimeter operations from 5G interference

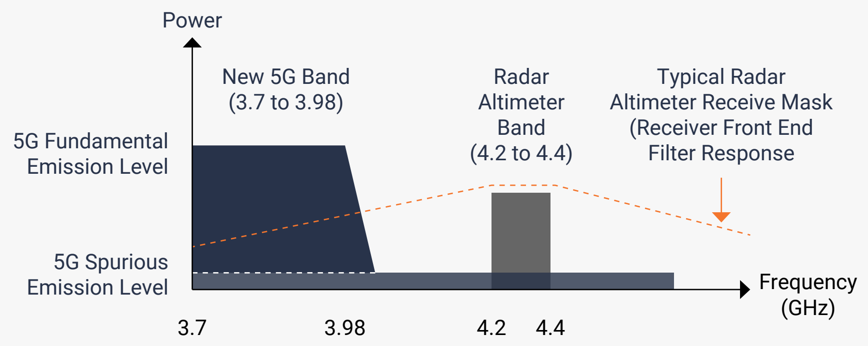
Radar altimeters are the only sensor onboard an aircraft that provides a direct measurement of the aircraft's clearance over terrain or other obstacles. This data is the most critical information in many automated landing and collision-avoidance systems.

Undetected failure of this sensor can lead to catastrophic results, which include false alarms that have the potential to undermine trust in the avionics systems. The challenge is to safeguard radar altimeter operations. The FCC has updated specifications to include a 20 MHz guard band between 3.98 to 4.0 GHz, which augments the existing buffer band extending from 4.0 to 4.2 GHz that is the upper limit of the radar altimeter spectrum.

Cellular networks that use the upper part of 3GPP Band N77 (C-Band) power levels could produce "emissions that may lead to blocking interference in the radar altimeter receiver, wherein a strong signal outside of the normal received bandwidth cannot be sufficiently filtered in the receiver to prevent front-end overload or other effects," according to an October 2020 RTCA Inc. report.

Also, spurious emissions from 5G base stations and user equipment can fall within the normal received bandwidth of the radar altimeter and may produce issues, such as desensitization due to reduced signal-to-interference-plus-noise ratio (SINR) or false altitude determination due to the erroneous detection of the interference signal as a radar return.

Radar altimeter band susceptibility to both 5G fundamental and spurious emissions



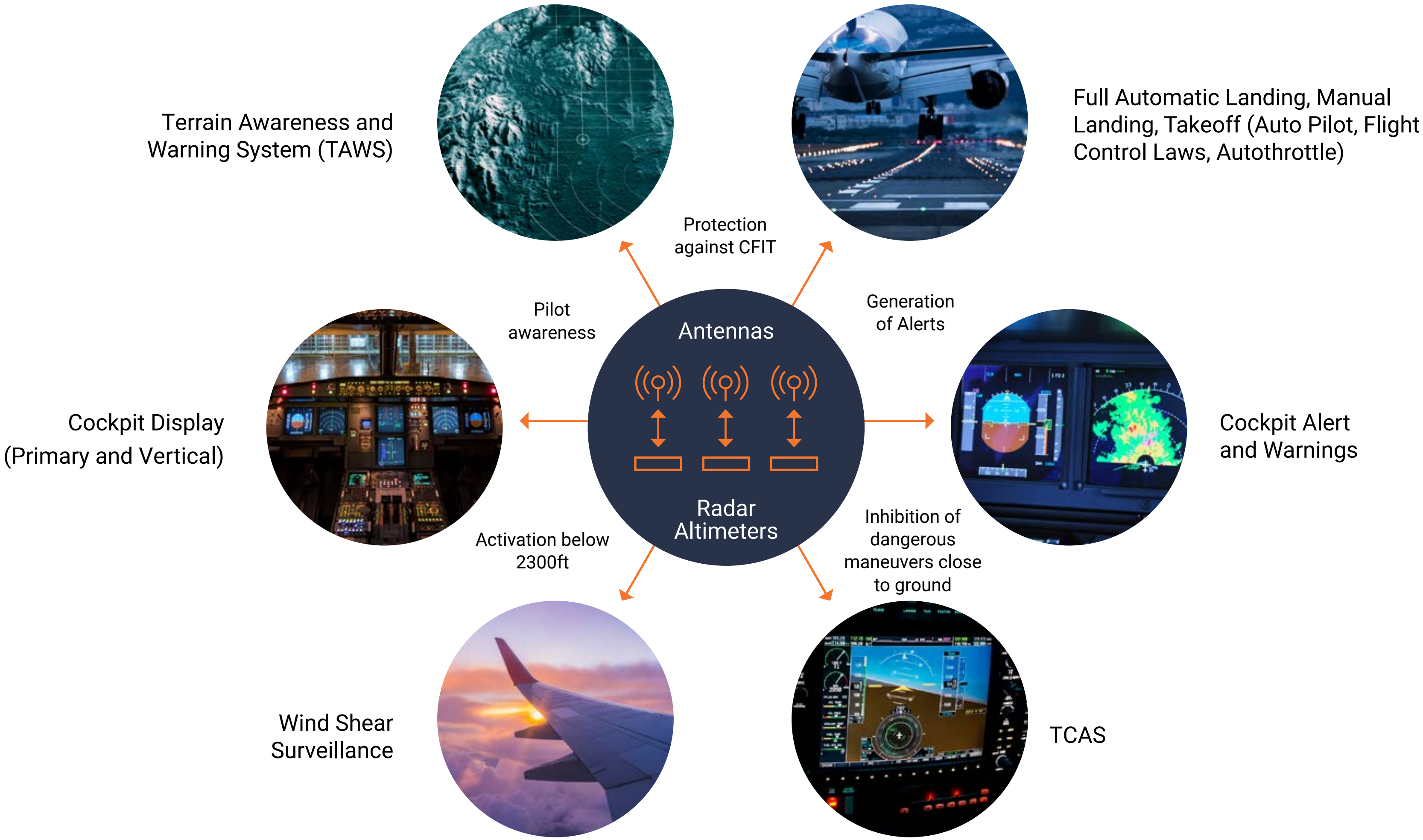
Did you Know?

The altimeter not only grabs altitude details but also detects wind speed/or direction over short distances in the atmosphere, which can be hazardous to planes.

Altimeters not fitted with 5G protection would force the plane's pilot to rely only on visual data during inclement weather, clouds, or fog that affect landings and take-offs.

What is driving the need?

Radar altimeters play a major role in providing aircraft with critical inputs from a wide range of aircraft systems and functions



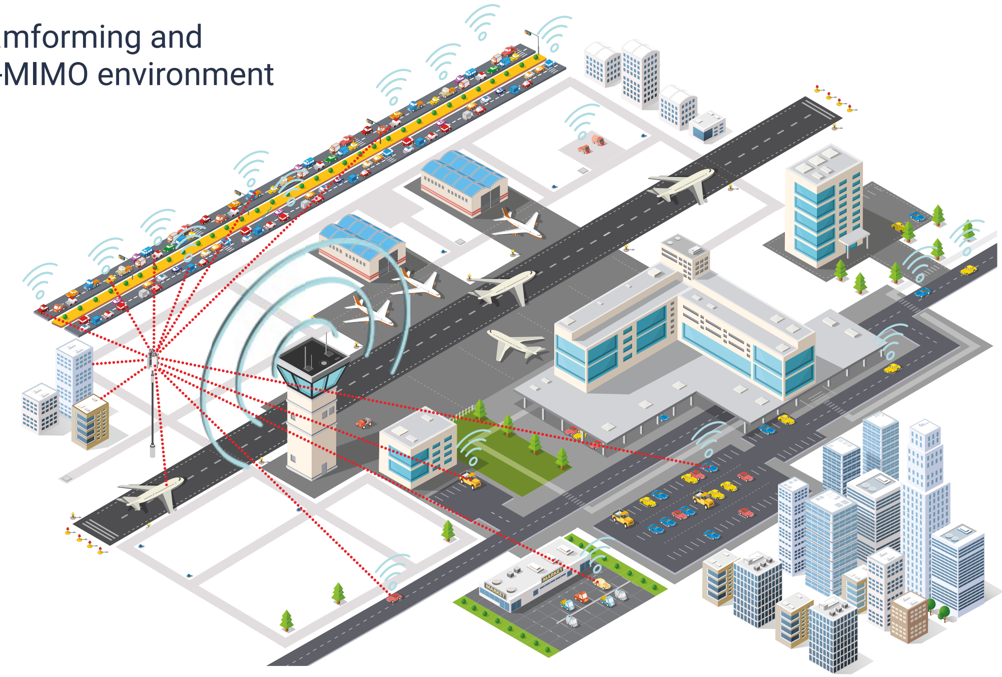
What is driving the need?

Potential 5G beamforming interference

When aircrafts are close to the ground during take offs or landings, the returned signals have a higher likelihood to be affected by stronger 5G C band signals. 5G cellular base stations operating in C-Band spectrum have a range of channels, or “blocks”, on which to operate.

In the US, the “C Block” 3.7 to 3.8 GHz is shared by Verizon Wireless and AT&T. All signals transmitted in this range must be -60 dB in amplitude at the upper and lower edges of the block in order to avoid interference to the adjacent spectrum user. This means the further a receiver is tuned away from the transmitter’s signal, the less RF energy could potentially interfere.

Beamforming and mu-MIMO environment



The illustration looks at beamforming operation focused towards specific user handhelds, vehicles, and drones. The beam signals are direct to each device and the signal level is increased to and from the devices to improve the reliability of the signal and/or improve the data speed. Each beam can effectively reuse the channel with different data at the same time through an active antenna and transmitter architecture called Multi-User Multiple Input Multiple Output or mu-MIMO. Another consideration is that bandwidth will vary from 10-100 MHz and thus increase the total amount of transmitted energy from the base station or devices in the direction of the radar altimeter.

One significant feature of 5G is an enhancement technique called “beamforming,” where wireless RF energy from a cellular base station is focused in a particular direction for a period of time in order to provide faster or more reliable data service to a mobile device. Hence, beamforming acts as a signal multiplier and could increase the signal power. This can increase the interference with the lower radar altimeter signals at greater elevations above ground level. This could be exacerbated if a radio- access point antenna installation is misconfigured, possibly creating spurious reflections and intermittent beamformed signals appearing in unintended directions.

What is driving the need?

Cell Phones on Planes

Although it may be frustrating at times, have you ever wondered why turning off your electronic devices and putting your cell phone in flight mode is such important ask of passengers for take off and landing?

The reason is to prevent new wireless access beamforming technology from focusing a wireless signal towards a specific receiving device onboard an aircraft and potentially sending a signal that may interfere with navigation, radar, ground communication, and collision avoidance technologies.

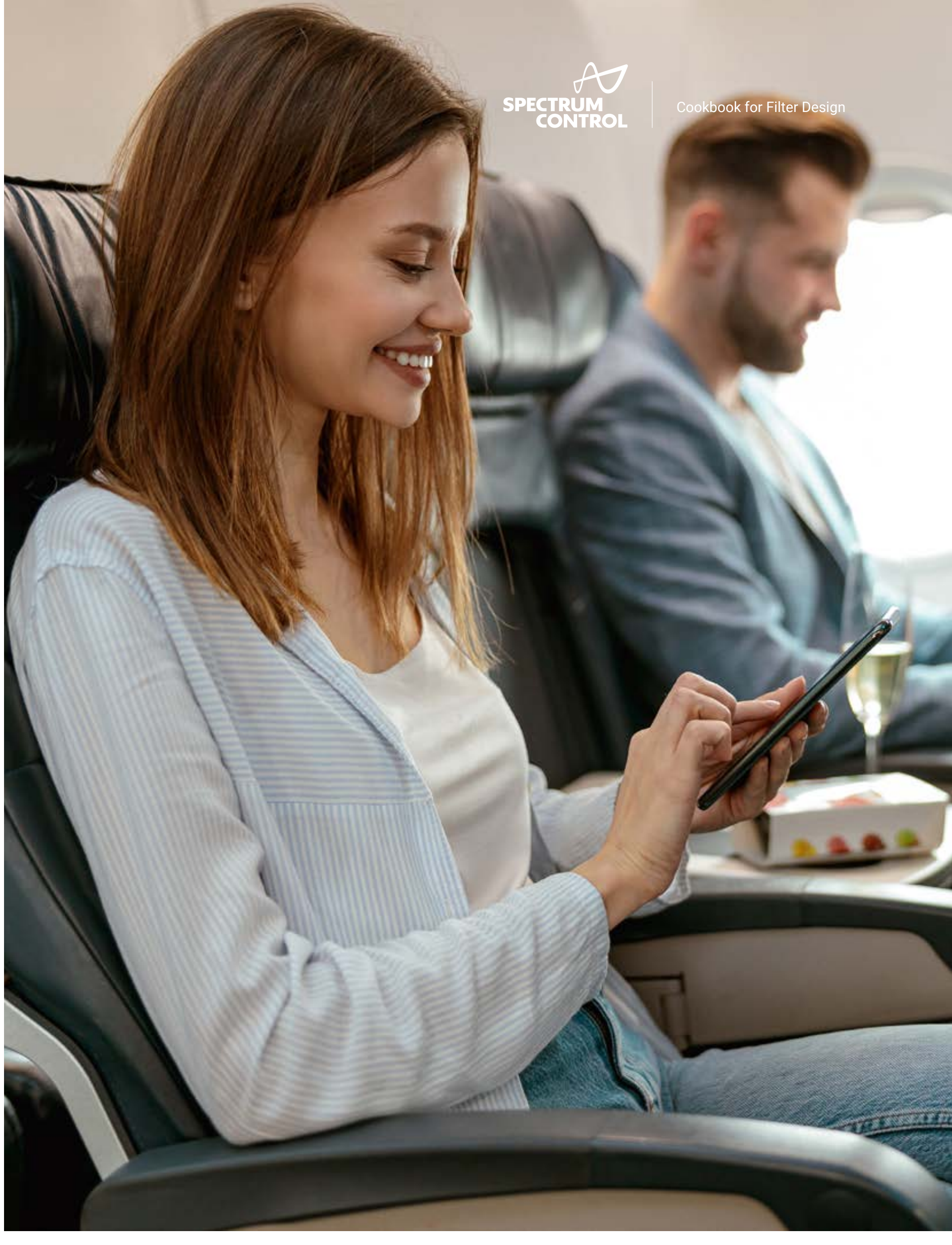
Did you Know?

How do radar altimeters operate?

A receiver transmitter (RT) working in conjunction with separate transmit and receive antennas makes up the majority of the system hardware.

Operation requires the RT unit to send a signal to the transmit antenna which is then directed to the ground.

When the signal hits the ground it is reflected back up to the receive antenna. The RT then performs a time calculation to determine the distance, as the altitude of the aircraft is proportional to the time required for the transmitted signal to make the round trip.



What is driving the need?

Other possible situations that can cause interference

1. 5G Multi-Carrier Operation includes multiple 5G wireless service providers that all operate in the same service area on their own channels within the C-Band. The combined effects of multiple RF carriers operating in semi-random fashion from one or separate locations needs to be measured and tested as a potential source of concern.

2. Coordinated MultiPoint (CoMP) 5G C Band based on transmission and/or reception at multiple separated cellular wireless sites with dynamic coordination among them. This could result in multiple cellular wireless sites transmitting at the same time, focusing on the same location, in order to enhance the service to a mobile device. This would elevate the RF levels at that point in space and could drive up the potential for interference.

3. The impact of Inter-Modulation Distortion (IMD), the mixing of RF signals operating within the C-Band and outside the C-Band, introduces another unknown set of use cases of concern. Specifically, those radio frequencies commonly found in operation in and around airports could mix with the C-Band cellular wireless signals and produce a potentially interfering RF signal to the radar altimeters as well as other RF-based operations, including navigation and communications.

4. As commercial mobile networks increase wireless capacity (further C-Band Spectrum Buildouts) this could drive plans for further use of the 3.7 to 3.98 GHz range. We also are seeing demand traction for the re-use of Citizens Broadband Radio Service (CBRS) spectrum from 3.55 to 3.7 GHz as well as from 3.45 to 3.55 GHz to build wireless networks based on 4G LTE and 5G cellular technologies.

5. Other spectrum auctions are planned worldwide for 3.1 to 3.4 GHz and to possibly make 3.4 to 3.45 GHz available to licensed or unlicensed cellular wireless or other wireless operations. The use of these bands, while being more spectrally distanced from the radar altimeters, could create an abundance for new potential sources of interference including:

   - Wideband Base Stations with unforeseen internal Intermodulation distortion (IMD) products.
   - Increased potential for misconfigured wireless base stations causing interference.
   - Defective operations could compound IMD from corrosion and other damage due to age.

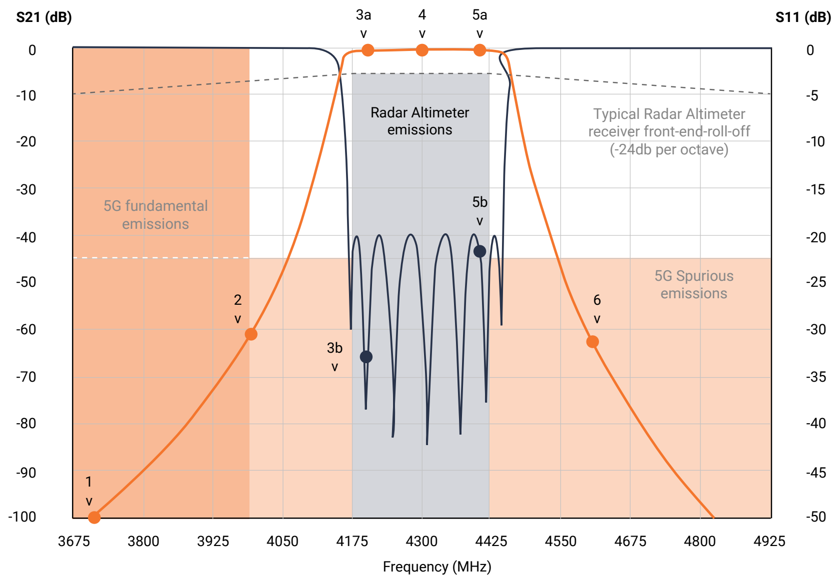
> "This is the first of many interference issues associated with higher frequency, broadband communications as wireless becomes the backbone of our ongoing digital transformation. Spectrum Control's core mission and targeted investments in RF protection address the broader issue of protecting critical electronics infrastructure from an increasingly dense, confused and overlapping electromagnetic spectrum."
>
> Ian Dunn
> Spectrum Control Chief Technology Officer

Filtering the way to safer C Band 5G

Spectrum Control's high-performance RF cavity filter solutions allow 5G C-band to take flight

The 5G altimeter filters need to suppress the primary 5G signals of 3.7 to 3.98 GHz. Depending on the required rejection, the insertion loss of a cavity filter can be 1.0 dB or less over an operating temperature of -55 to +85 degrees C.

The main problem is not due to the spurious emissions of the 5G transmitters. The 5G signal are typically very clean and limited to the allocated band. The problem is the altimeter front-ends are not sufficiently band limited and the 5G signals can overwhelm the altimeter signals that are at 4.2 to 4.4 GHz.



1. 3700 MHZ
   -100.922 dB
2. 4000 MHz
   -59.33 dB
3. 4200 MHz
   a. -0.61 dB b. -33.208 dB
4. 4300 MHz
   -0.48 dB
5. 4400 MHz
   a. -0.63 dB b. -21.607 dB
6. 4600 MHz
   -62.226 dB

The filter needs to be capable of suppressing the fundamental emissions with sharp selectivity outside the 4.2 to 4.4 GHz band to ensure safety margins are met for aircrafts flying within range of a radio access network broadcasting 5G C Band service.

For example, Spectrum Control's high-reliability BOM10648 cavity filter is designed to solve the emerging 5G C-band interference problem. The passband of 4.2 to 4.4 GHz has less than 1 dB insertion loss and greater than 50 dB of signal rejection over the 3.7 to 3.98 GHz band and 55 dB of rejection at 4.6 GHz. In addition the group delay variation is less than 2 nsec. over the passband. The filter housing is 1 inch square X 4 inches long excluding the TNC connectors. Threaded mounting provision is also provided.

A cavity based design was utilized for this application because of the inherent high Q/ low loss of cavity filters and the need to keep the insertion loss as low as possible as not to compromise altimeter performance.

Interference Frequency (GHz)	RF Filter Attenuation (dB) without Spectrum Control filtering
≤4.2	Attenuated at 24 dB per octave to a maximum of 40 dB
4.2	0
4.3	0
4.4	0
≤4.4	Attenuated at 24 dB per octave to a maximum of 40 dB

Source: ITU-R M-.2059

How Can We Help You?

Conquer this issue – special filters design support methodology to prevent a frequency clash

Spectrum Control focuses on all aspects of special filter environment design. Our design approach starts from your priorities - insertion loss, rejection and formfactor. We will work with you to consider a wide array of trade-offs to deliver a filter optimized for a particular application. Contact us with your specialized needs.

Industry standards and recommendations (ICAO, ITU, 3GPP)

What are the RF parameters to be considered for a 5G Altimeter:

1. Passband frequency
2. Maximum insertion loss over the passband
3. Maximum group delay variation over the passband
4. Stopband frequency
5. Minimum attenuation over the stopband
6. Power Handling

What are the physical constraints to be consider for the 5G Altimeter filter:

7. Maximum allowable size
8. Connector type
9. Do the units need to be hermetically sealed

Interference modelling (expected 5G interference power at the radar altimeter RX port in various scenarios

Empirical interface tolerance threshold testing (5G interface susceptibility limits at the radar altimeter RX port) for parameters 1-9.

Then assign any absolute min./max. limits and priorities (1-4) for parameters 2, 3, 5, 7.

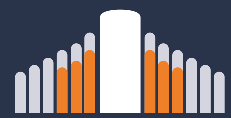
Consider trade-offs between parameters 2, 3, 5, and 7.

It is acceptable for some parameters to be N/A or don't care.

Computed interference Levels

Safe interference limits

Consider trade-offs between parameters 2, 3, 5, and 7.



Identification of scenarios affected by interreference and associated impacts on Radar Altimeter operation

Evaluation test sample

Contact us

Please get in touch if you would like to talk to us about anything related to 5G & Wi-Fi spectrum innovation.

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