Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of Spectrum Task Force Requests Information on Frequency Bands Identified By NTIA As Potential Broadband Spectrum	))))))))	ET Docket No. 10-123

COMMENTS OF AVIATION SPECTRUM RESOURCES, INC.

Aviation Spectrum Resources, Inc. ("ASRI") hereby submits comments on the Spectrum Task Force Request for Information on Frequency Bands Identified by NTIA as Potential Broad Band Spectrum. ASRI will confine its comments to the designation of the 4200-4220MHz and 4380-4400 MHz portions of the Radio Altimeter band as candidates for commercial broadband use.

ASRI, as the successor to Aeronautical Radio, Inc. ("ARINC"), is the communications company of the air transport industry, acts as the industry licensee in the aeronautical enroute and fixed services, and serves as the industry frequency manager for United States civil aviation.[1] As such, ASRI is the licensee for more than 5,000 aeronautical enroute stations and is responsible to the FCC and the industry for the effective and efficient use of those resources for

[1] ASRI is owned by members of the civil aviation community. The board of directors of ASRI is advised in spectrum management matters by the Aeronautical Frequency Committee, which consists of members from the major passenger and cargo air carriers, the National Business Aircraft Association ("NBAA"), the Aircraft Owners and Pilots Association ("AOPA"), SITA, ARINC, and the Helicopters Association International ("HAI"). In addition, non-voting representation is held by the International Air Transport Association and the Air Transport Association of America.

the safe and economic operation of aircraft in U.S. airspace.

A review of the NTIA Fast Track Study reveals little justification or analysis that supports the designation of the 4200-4220 MHz and 4380-4400 MHz bands as being available or suitable for broad band applications. It would appear from the study that NTIA made its determination on the suitability of these bands merely by counting the number of frequency assignments and the geographic extent of operations based on the licensed activity. The fact that Radio altimeters are not individually licensed and there is no ground component apparently did not enter into the analysis. The Radio Altimeter, along with other avionics on an aircraft, is licensed either by rule, aircraft license or fleet license for the larger commercial carriers and cargo aircraft. A review of the Government frequency license database or the FCC Universal Licensing System will not indicate any radio altimeter licenses in the 4200-4400 MHz band other than those for ground based test equipment. However that does not mean that the band is unused or underutilized.

The Radio Altimeter System

The Radio Altimeter System provides accurate terrain clearance altitude information, displayed on the flight deck for use by the flight crew. It also provides input to interfacing flight management systems where radio altitude is used in various computations or for the establishment of flight conditions required for the auto pilot and for warning annunciations such as the ground proximity warning system or the terrain avoidance warning system (TAWS).

The Radio Altimeter System consists of two (2) to three (3) identical Radio Altimeter Receiver/Transmitter (R/T) units with their associated equipment. All R/T units operate simultaneously and independently from one another. The radio altitude is computed from the time interval a transmitted signal needs to travel to the ground and return to the airplane after reflection from the ground. Most modern civil radio altimeters employ Frequency Modulated Continuous Wave (FMCW) signals. Radio altimeters designed for use in automated landing systems are required to achieve an absolute range resolution of less than 0.9 meters (3 feet). In order to avoid altimeter to altimeter jamming on the same aircraft the center frequency of each altimeter is offset by at least twice the IF bandwidth to prevent false tracking or jamming by the adjacent altimeter.

Radio Altimeters designed for use in automated landing systems are required (Eurocae ED 30 and ARINC 707-7) to achieve an absolute range resolution of less than 0.9 Meters (3 feet). The Range resolution for an FMCW altimeter is proportional to the bandwidth of the signal as demonstrated in the following formula:

$$Range\ Resolution(rr) = \frac{c}{2 * BW}$$

Or

$$Bandwidth\ (BW) = \frac{c}{2 * rr}$$

This assumes an ideal oscillator with little or no drift. Oscillators that are being used in the latest designs have a frequency stability of 10 parts per million per degree C (ppm/C) while the older designs have frequency stabilities of between 25 and 50 ppm/C. The radio altimeter operates over a temperature range that varies by 90 degrees C thus with a center frequency of 4300 MHz you would see a maximum frequency drift of between 3.9 and 11.6 MHz. This would result in a required 3 dB bandwidth between 170.4 and 178.1 MHz.

The ITU Radio Regulations require that at the edge of the allocated band the signal is at least 40 dB down from the primary signal. Recommendation ITU-R SM.1451 specifies for a FMCW signal that the 40dB bandwidth be:

$$BW_{-40} = 0.0003F_c + 2B_d$$

Where: $F_c = Centre\ frequency$

$B_d = Deviation\ bandwidth$

Assuming that 2Bd equals the 3 dB bandwidth then the 40 dB bandwidth can be calculated to be between 181.7 and 189.4 MHz.

See the attached independent analysis by Honeywell Fellow David Vicanti. (Attachment A)

Radio Altimeter Equipage

The 2010 US fleet consisted of approximately 3,713 mainline US carrier jets, 1,771 regional jets, 806 Cargo aircraft 17,937 business aircraft, and 224,172 general aviation aircraft. Assuming that the general aviation fleet is not equipped with radio altimeters that operate in the 4200-4400 MHz, and only looking at the mainline carriers, regional jets, cargo carriers and business aircraft; there are approximately 24,227 aircraft in the USA that are equipped with 4200-4400 MHz radio altimeters. The cost of one radio altimeter according to IATA is $60,000 and with installation and antenna $80,000. It is assumed that 10% of the US mainline carrier jets are wide body aircraft that require 3 radio altimeters per aircraft. The remaining 3342 air carrier jets, plus 1,771 regional jets, 806 cargo aircraft are assumed to be equipped with the FAA minimum 2 altimeters per aircraft. The remaining 17,937 business aircraft are assumed to be equipped with a single radio altimeter. The total fleet equipage is then 27,346 radio altimeters at $ 80,000 per installation or a total radio altimeter investment of $2,187,680,000. These estimates are not representative of the worldwide aircraft fleet and are only an attempt to approximate the economic investment by the USA aircraft operators.

CONCLUSION

Based on a radio altimeter that is designed to meet the minimum required range accuracy, allowing for frequency drift due to variations in temperature and the need to have up to 3 radio altimeters the theoretical minimum bandwidth requirement for proper Radio Altimeter operation is between 181.7 and 189.4 MHz.

Considering that there were no technical assumptions upon which NTIA based its analysis and considering that the entire band is necessary for the safe operation of aircraft, in the most critical phases of flight, ASRI recommends that the Radio Altimeter band be removed from consideration for Broadband purposes.

Respectfully submitted,

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Attachment A

Broadband Communications Usage

of the 4.200 – 4.220 and 4.380 – 4.400 GHz Altimeter Band

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INTRODUCTION

This paper is intended to address the serious impacts of interference or denial of normal operation of Radar Altimeters aboard Commercial Aircraft.

Radar Altimeters are a critical portion of the FAA designated Minimum Equipment List that must be provided on all aircraft commercially licensed for passenger service. Furthermore Radar Altimeters are required to be certified at Safety Criticality Rating of Level A for all Commercial Transport Aircraft and Level B for Business and Regional aircraft. Where Safety Criticality Level A is defined by the FAA DO-178B / DO-254 as: *Where a software/hardware failure would cause and or contribute to a catastrophic failure of the aircraft flight control systems.* Level B safety criticality is defined as: *Where a software/hardware failure would cause and or contribute to a hazardous/severe failure condition in the flight control systems.* In other words, incorrect altitude data can cause the loss of an aircraft with all souls aboard. This is not conjecture but is a demonstrable fact that caused the recent loss of a modern Next Generation transport Jet with all aboard.

In the case of Commercial Transport Aircraft provided by Boeing, Airbus, Embraer, Dassault and others, Radar Altimeters are directly coupled to the critical Flight Control System or Autopilot. The altitude measurement response characteristics of the Radar Altimeter has been carefully honed and has specific characteristics listed in international industry specifications (DO-155, ED 30) that must be met before any Radar Altimeter product can be certified for sale or use.

Radar Altimeters are crucial to all transport aircraft descent from at least 2500ft of altitude and to as high as 8000ft of altitude. Should a Radar Altimeter be confused by interference from broadband communications sharing the altimeter band it can cause erratic behavior of the aircraft. In the most recent crash scenario one of two altimeters carried by the 737 incorrectly measured the altitude as being well below 100ft when in fact the aircraft was still near 3000ft. But this data caused the Autopilot to retard the engines to idle, deploy wing flaps for landing and lower the landing gear. With the aircraft at 3000ft and a sudden reduction in thrust and a dramatic increase in drag due to the lower landing gear, the aircraft stalls in flight and must be recovered by quick action of the pilots. If they cannot retract the steps of the autopilot and rapidly increase engine thrust, the aircraft is doomed and will crash.

Similarly, if the altimeter should be jammed by nearby broadband communications devices to the point where the received noise level makes detection of its own signal impossible, the aircraft will be denied crucial height above ground information and will be in grave danger, especially on night or degraded weather conditions. There is no other source of height above local terrain that is available to the aircraft. Barometric altitude and GPS (GNSS) altitude measure height above an "average" sea level or above the ellipsoid model of the shape of the earth. Obviously, landing at airport facility at Denver Colorado, where the airport surface is 5000ft above sea level will create a serious problem in attempting to land an aircraft by Barometric Altitude. If the aircraft crew itself is not capable of literally seeing and estimating height above terrain, the aircraft cannot land and must find an airport with adequate visibility.

Therefore any attempted use of the radar altimeter band by other than radar altimeters themselves places the lives of all commercial aircraft passengers in jeopardy. This paper will establish the characteristics of existing and newly developed radar altimeters and the potential for either denying or disrupting the normal behavior of those altimeters should they be exposed to modern spread spectrum, TDMA, FDMA, GSM or other means of digital modulation methods commonly employed by broadband communications devices.

This paper also wishes to point out that by virtue of the fact that radar altimeters are always directed at the ground with a wide 40 – 60 degree beamwidth, they are highly vulnerable to interference from potentially numerous sources of co-band communications devices and the level of interference will increase with EITHER increasing altitude (increased number of observable transmitting sources in the main beam OR decreasing altitude with reduced distance to radiating communications devices, just as the altitude information becomes increasingly more critical for safety of flight. There is nothing to prevent communications devices from being used directly under the vast majority of the entire approach path for landing in cities and urban areas. Not only that but one can assume that with the encourage proliferation of these systems that the threat to normal and reliable operation of altimeters would increase over time.

RADAR ALTIMETER MODULATION & RECEIVER SENSITIVITY

All commercial radar altimeters in use today make use of a radar modulation method known as Linear Frequency Modulation – Continuous Wave or LFM-CW or FM-CW. This modulation waveform is used as the least complex way to provide exceptionally accurate altitude measurements at the critical very low altitudes before touchdown. This accuracy is required to provide smooth continuous data to the flight controls and autopilot for automated landings in poor weather. This data is critical in CAT II and CAT III landings when the pilots view of the runway is restricted to 50 feet above the runway and finally zero visibility in CAT III autoland conditions.

All commercial transport aircraft autopilots and flight controls have been carefully developed and refined over many years to expect this well known altimeter behavior. There is no other source of aircraft height above the ground data for common IFR or VFR flight conditions.

All commercial transport and all business aircraft licensed to fly for hire carry at least two radar altimeters for use in final approach in both visual and instrument flight rule conditions.

All altimeters supplied by Honeywell are place essentially in the middle of the 4.2 – 4.4 GHz band and use small bandwidths at the edges of the band to provide room for frequency drift. The majority of the several thousand altimeters sold by Honeywell alone over the last two decades do not use closed loop frequency control or crystal oscillator based precision stability reference oscillators. The NTIA should therefore expect that it is entirely possible to expect altimeters from Honeywell and other suppliers to routinely occupy the band edges being considered for re-use as communications applications.

By the physics of their design FM-CW radar altimeters have exceptionally sensitive receivers with minimum detection thresholds between -110 dBm and -120 dBm. FM-CW radar systems are “homodyne” systems that sample a fraction of the currently transmitted waveform and supply it as a reference to the receiver mixer. This configuration directly downconverts all received signals directly to a baseband receiver. While the signal processing bandwidth of the typical radar altimeter may be less than 100 Hz per altitude range bin, the overall receiver bandwidth can be several MHz wide depending on chosen frequency modulation rate and the altitude delay time. All FM-CW radars measure range to a target via a linear relationship of the spectral frequency of the target in the wide band receiver bandwidth. The higher the spectral frequency of a detected target the greater the range to the target and the lower the spectral frequency of a target in the receiver pass band, the shorter the range.

All FM-CW radar target detection and range determination is accomplished via spectral analysis. Older altimeters use a simple method of “counting zero crossings” as a means of computing the dominant signal frequency rather than the digital processing technique of Fast Fourier Transform processing or FFT. This was done many years ago to provide simple low cost altimeters for a large segment of the market place. Only recently has there been a general transition from the simple “zero crossing” counting method to the FFT processing method though some altimeters have used it for a long time, though in a very limited form.

It should be understood then that any interference that can mix with the linear FM waveform that varies in the form of a triangle or “sawtooth” and produce spectral components within the receiver pass band has the potential to cause any altimeter to dangerous false altitudes.

In those cases where the interfering modulation is effective spread across many MHz of bandwidth as it mixes with the linear FM reference in the receiver mixer the effect is to raise the noise floor of the FM-CW radar receiver incrementally by the contribution of each received radiator. It is crucial to understand that the linearly varying FM causes a relatively narrow band carrier that falls within or nearby to the edge of the altimeter modulation to be swept through some fraction of the radar altimeter receiver passband.

Modulation rates of most altimeters cause the entire swept bandwidth of up to 170 MHz to be transmitted in 0.01 and 0.001 seconds. These modulation periods are thousands of times longer than typical pulsed radar systems.

ALTIMETER ANTENNA PATTERN

All radar altimeters use a commonly known antenna design that provides 9 to 11dBi of gain over an isotropic radiator and between 45 and 60 degrees of coverage to the 3 dB point (half power) of the antenna pattern. These wide antenna beams are made necessary by the wide range of pitch and roll angles that can be performed by an aircraft on takeoff or landing. The antenna pattern is essentially cone shaped and is linearly, horizontally polarized. However the actual orientation of the H polarized radiation in terms of pointing N, S, E, W depends entirely on the flight vector of the aircraft. Cross polarization isolation to vertically polarized signals is not specified in any production radar altimeter antenna and cannot be depended on to provide any measure of protection to the altimeter from jamming by choosing a vertically polarized transmission from a Wi-Fi device. Neither can we depend on users of the Wi-Fi device to orient the device so that its transmitted polarization is not horizontally polarized because use may allow virtually any linearly polarized orientation and Polarization purity in Wi-Fi radiators is not carefully controlled.

The fact that all radar altimeters are necessarily pointed at the ground makes them vulnerable to ALL of the possible Wi-Fi sources illuminated during approach. The radar altimeter does not have the benefit of being shielded or screened from many of the possible sources by propagation among urban building canyons by operating at the same altitude as all other sources. Instead it can virtually "see" all possible radiation sources as they escape buildings via windows and via direct transmission from devices operating outside of any structure.

FMCW MODULATION INTERACTION WITH CARRIERS

Linear triangle wave Frequency Modulation employed by virtually every radar altimeter in production and in operation, causes a fixed unmodulated carrier to be "swept" across its receiver pass band as the instantaneous frequency of the radar approaches within +/- the TOTAL receiver bandwidth. Therefore if a radar altimeter has a 2 MHz wide total receiver bandwidth (refined into spectral bins via an FFT) overlaps just the last 2 MHz of the maximum or minimum frequency of the linear FM waveform, the two signals will cause the energy of the fixed carrier to be swept across the entire bandwidth of the receiver TWICE. Once as the Linear FM approaches the fixed jammer frequency from below and once as it departs the fixed jammer frequency for higher frequencies. This means that if Wi-Fi devices were to occupy the band edges of the radar altimeter band and to slightly overlap with an older altimeter as it drifted into the proposed Wi-Fi regions, it would cause power to be swept across its entire receiver band for each received jammer.

We can expect that a large number of jammers interacting in a random fashion with the linear FM waveform can be expected to produce dramatic inter-modulation features and rogue spectral components to be computed in the altimeter signal processing steps of zero crossing or FFT processing.

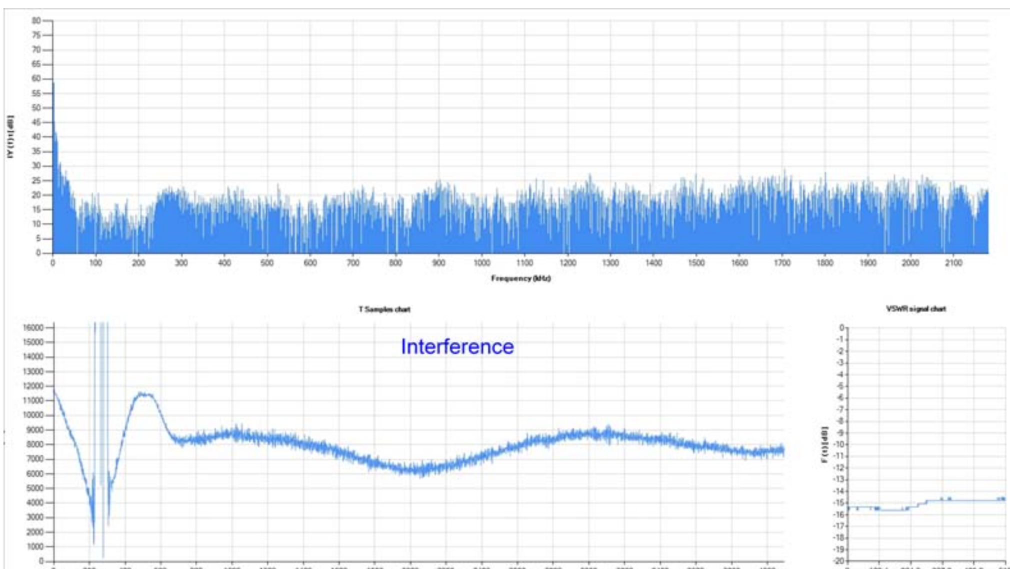
While there may be some benefit to the fact that the jammer energy is swept through the receiver pass band in a fraction of the total modulation period, it has been demonstrated that this can cause exceptionally sharp receiver saturation to occur. Receiver saturation in a receiver operating at frequencies as 100 Hz has serious long term effects. The receiver cannot recover to normal operation for at least 5 times the inverse of the lowest receiver frequency. All FM-CW radars directly convert to baseband and must resolve frequencies equal to at least 1/ modulation time period in order to measure the very smallest altitude required of the altimeter (3 – 5 feet). This means that despite the fact that the Wi-Fi modulation interacted with the swept linear waveform for just 10 – 20% of the swept bandwidth, the receiver will remain "captured" in saturation with no sensitivity for at least 5 times the modulation interference time. This is a well known physics calculation for the decay time of a typical Resistor – Capacitor etc circuit.

DEMONSTRATED NEARBY INTERFERENCE EFFECTS

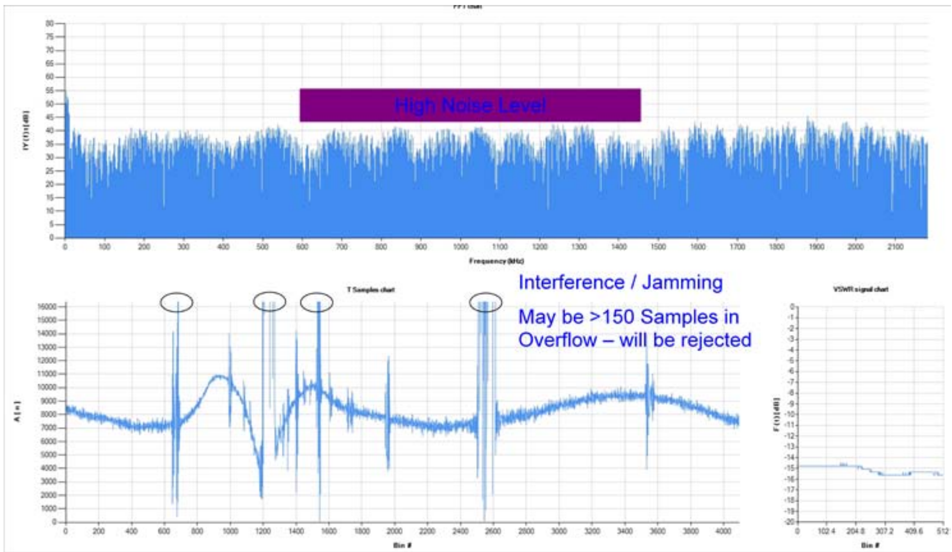
The following images are real measured interference effects on an FM-CW radar altimeter. It can be seen that while a single very strong interfere may not cause false altitudes the signal can be so strong as to cause complete capture of the receiver for the entire modulation period despite the fact that it only existed within the receiver pass band for a fraction of the modulation period. This kind of single high power jamming causes loss of track and affects receivers with AGC or with pre-compensated range loss settings. This is denial of operation.

When many lower power transmitters exist at the same time, the result is intermixing among the numerous signals such that rogue random spectral components are generated that can occupy the entire radar altimeter receiver bandwidth. This will cause false altitude computation and is exceptionally hazardous. A modern advanced altimeter now under development at Honeywell will ignore this condition and void the measured data, but if the condition persists, it will also lead to denial of operation and the altimeter will indicate no altitude can be computed or if jammed for a long time may indicate a failed condition warning.

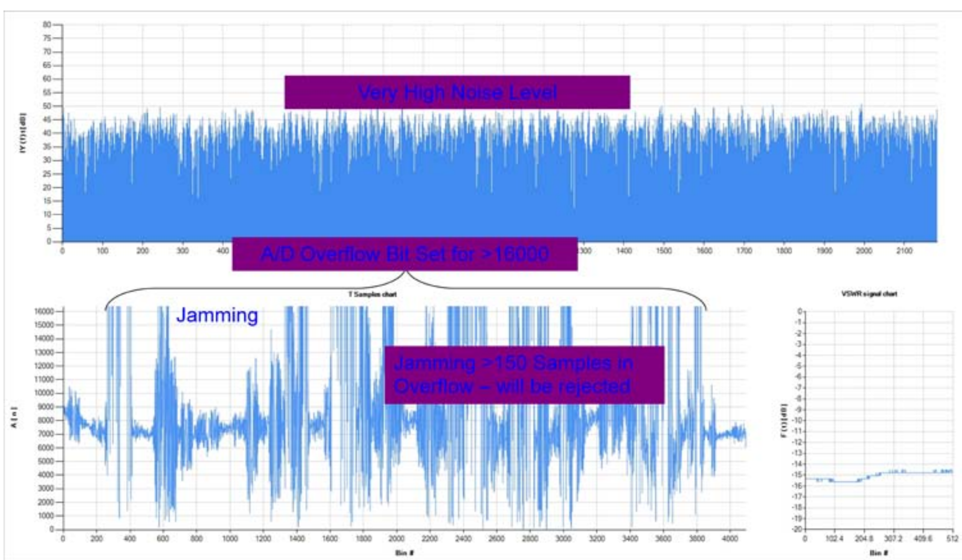
The following figure demonstrates the effect of a single strong carrier crossing the radar altimeter for a fraction of the modulation time period between 200 – 300 digital samples plotted along the x axis in the left hand lower plot. The short period interference captures the receiver and suppresses the noise output shown in the FFT output in the upper plot. In all cases the jammers in this discussion are WIDEBAND systems (>100 MHz) and not narrow band carriers. These examples can be considered indicative of the type of interference we can expect if broadband digital communications devices are allowed to proliferate within the wide beam view of a radar altimeter looking constantly at the ground from an aircraft platform.



The following image demonstrates what happens with just two jamming sources crossing the swept altimeter bandwidth for a fraction of the time. Sampled data showing the large data spikes caused by the two jammer sources creating additional intermodulation products so that it appears that many jammers are present. These two jammers cause a dramatic increase in the receiver noise floor and reduce sensitivity by as much as 10 dB. The upper plot is the FFT spectral analysis output plotted in spectral frequencies and amplitude.



The following example demonstrates the effect of multiple jammers crossing the swept signal bandwidth and then creating multiple intermodulation effects. The noise floor has been completely destroyed and the number of A/D samples that are in saturation as the receiver is also saturated approaches a large fraction of the total data collection period. This data is unusable and if not detected and eliminated by the altimeter will cause serious operational problems.



EXPECTED POWER LEVEL AT RADAR ALTIMETER

The Friis Equation computes the power received at a radio from a transmitting source based on antenna gain, operating wavelength and distance travelled. The equation is written as:

$$Pr = PtGtGr\left(\frac{\vartheta}{4\pi R}\right)^2$$

Where Pr= Power Received, Pt = power transmitted, Gt = transmit antenna gain, Gr= receive antenna gain,ϑ = Wavelength in meters, R is distance between the antennas in meters.

All radar altimeters use a pair of antennas with a fixed gain between 9 and 11 dBi. If we assume that a small WiFi device uses a 0 dBi gain antenna for omni-directional broadcast capability at the band edges of the radar altimeter band and that Wi-Fi device transmits 10 milliwatts (0.01 watts) then the total received power across the digital modulation bandwidth at 6000 feet will be -90.35 dBm. This power level can be as much as 30 dB above a -120 dBm noise floor in a typical radar altimeter.

While we can expect the power spectral density of the Wi-Fi broadcast to be reduced, it would have to be spread across bandwidth by a factor of 1000:1 to place the power of a single Wi-Fi device at the noise floor of the radar altimeter receiver.

Now consider that a radar altimeter beamwidth is between 45 and 60 degrees to allow accurate altitudes to be measured when the aircraft rolls as much as 35 degrees and pitches as much as 25 degrees. This very wide beam now covers as much as 80% of a square mile at 6000 feet altitude. Within that area in an urban area as an aircraft prepares for a landing we might expect to be exposed to hundreds of Wi-Fi devices occupying the illuminated area of the altimeter beamwidth. All of this power will at a minimum combine to directly raise the noise floor of the victim altimeter by as much as 20 dB, thereby dramatically reducing sensitivity.

If on final approach at 500ft altitude where attempting to recover from a false altitude or the loss of altitude measurement capability in CAT II or CAT III conditions becomes exceptionally dangerous a single 10 milliwatt transmitter were to illuminate a victim altimeter, -68 dBm of power could be received. This is nearly 52 dB (158,000:1) above the -120 dBm noise floor and has the great potential to generate false spectral content in the FMCW radar receiver rather than just raise its noise floor. This signal could under some conditions of high Automatic Gain Control (AGC) settings cause the radar altimeter receiver to saturate. The AGC will "attack" the strong interfering signal and dramatically attenuate ALL signals present at the receiver and potentially result in total loss of track of the ground target in the receiver. Even if the Wi-Fi digital modulation bandwidth causes the transmitter power spectral density to be spread by a factor of 1000:1, there will remain a 22 dB (158:1) detriment to the Radar altimeter receiver and the AGC or other functions of the altimeter may be adversely affected.

ALTITUDE RESOLUTION AND REQUIRED BANDWIDTH

Radar Altitude resolution is defined as $\nabla R = c \; / \; ((2 \times Bandwidth) \;)$ where Bandwidth refers to the amount of linear frequency modulation in Hertz and c is the speed of light in meters per second. Specifications for Commercial Transport Altitude Accuracy found in industry document DO-155 within 1.5 feet at or below 75ft of altitude and within 3 feet at or below 150 ft of altitude. These accuracy levels were determined from requirements for safety and smooth reliable performance for every landing under all visibility conditions.

The above calculation then reveals that to resolve 3ft of altitude range requires 164 MHz of modulation bandwidth. In order to reach 1.5 ft resolution would have required 328 MHz of operating bandwidth, but that is not available within the legal band. To reach 1.5 ft resolution requires "sub-resolution" of the data by signal processing means. But this sub-resolution is only possible with exceptionally high signal to noise ratios and over the flat surface of the runway at low altitudes.

It is not possible to sub-resolve altitude above an arbitrary ground surface at higher altitudes away from the runway in order to reduce required operating bandwidth. Low altitudes above a runway can be sub-resolved because the runway is the only object within the altimeter field of view and the reflection is “specular”, meaning it is highly centralized and consists of a very limited altitude extent with an exceptionally high reflectivity. Over an arbitrary earth surface the altimeter records an altitude extent that can range from tens of feet to hundreds of feet. The altimeter must determine the true altitude from this extended set of data. The magnitude of the reflectivity over a country side or urban city area can vary over 60 dB (1million to 1) instantly from one moment to the next, making it impossible to provide further resolution below that made possible by the available modulation bandwidth.

UNIT TO UNIT JAMMING PREVENTION – FREQUENCY OFFSET

It is also necessary for aircraft to require up to 3 radar altimeters to be simultaneously operational on the same aircraft. Multiple altimeters are required to provide protection against false altitude data being accepted by the autopilot or flight control system is less than 1 in 1Billion. In order to allow three simultaneous altimeters to coexist within a few feet of each other, each of the altimeters must operate at a small center frequency offset of at least 2 times the bandwidth of the receiver to avoid interference among the altimeters. Mutual interference among the altimeters can result in total loss of output from an altimeter or a false altitude. Altimeter designers have set this offset frequency among the altimeters to be approximately 5 MHz across industry. Large aircraft installations with three altimeters require 10 MHz of frequency offset to assure proper operation of all three altimeters.

FREQUENCY STABILITY OF EXISTING ALTIMETERS

The vast majority of all radar altimeters flying today are based on “open loop” linear Frequency Modulation of a Voltage Controlled Oscillator (VCO) that operates at a center frequency of 4.300 GHz with frequency stability of +/-15 MHz over -40 to +70 Degrees C temperature variation that can occur aboard the aircraft. Only the most recent altimeters used aboard all new aircraft such as the 787, A350 or A380 have digitally synthesized or reference crystal stabilized modulation. There are well over 10,000 aircraft flying with “open loop” VCO systems in their radar altimeters. These open loop designs are reliable and remain in full production as of this writing.

TOTAL REQUIRED ALTIMETER BANDWIDTH

In the paragraphs above we have indicated the various needs of operating frequency bandwidth to allow for each altimeter issue of altitude accuracy

The total bandwidth is: 164MHz Resolution + 10MHz Multiple Altimeter Offset +15 MHz Frequency temperature stability results in a total 189MHz with the remaining 11 MHz of bandwidth reserved for 5.5 MHz wide “guard bands” at the band edges to assure that the minor sidebands created by the altimeter do not intrude on adjacent band users and similarly to avoid adjacent band users that might otherwise interfere with normal altimeter operations.