Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	)	
Amendment of Parts 1, 2, 15, 90 and 95 of the Commission's Rules to Permit Radar Services In the 76-81 GHz Band	)	**ET Docket No. 15-26**
Amendment of Part 15 of the Commission's Rules To Permit the Operation of Vehicular Radar Services in the 77-78 GHz Band	)	**RM-11666**
Amendment of Sections 15.35 and 15.253 of the Commission's Rules Regarding Operation of Radar Systems in the 76-77 GHz Band	)	**ET Docket No. 11-90** **RM-11555**
Amendment of Section 15.253 of the Commission's Rules to Permit Fixed Use of Radar In the 76-77 GHz Band	)	**ET Docket No. 10-28**
Amendment of the Commission's Rules to Permit Radiolocation Operations in the 78-81 GHz Band	)	**WT Docket No. 11-202**

COMMENTS OF MANTISSA LTD.

Mantissa Ltd. ("Mantissa") is a developer and manufacturer of miniature fixed radar sensors for perimeter security, currently designed for operation in the 76.0-77.0 GHz spectrum band. Mantissa firmly believes that millimeter wave fixed radar offers significant advantages over other perimeter security technologies currently available to government and commercial users, and poses a minimal risk of interference with other permitted uses in the same spectrum bands. For this reason, Mantissa applauds the Federal Communications Commission (the "Commission") for initiating its Notice of Proposed Rulemaking in the above-referenced docket and the Commission's proposal to enable fixed radars operating in the 76.0-77.0 GHz band, and urges swift action by the Commission to approve the proposed rules.

Introduction

Mantissa appreciates this opportunity to comment on the Commission's proposed rules as applied to fixed radar. Specifically, Mantissa addresses in these Comments the important security applications for fixed radar, the compatibility of vehicular radars and fixed radars, and the prudence of allowing shared use throughout the 76.0-81.0 GHz band.

Table of Contents

<u>About Mantissa's Miniature Fixed Radar Devices</u>

The product for which Mantissa currently desires to use the 76.0-77.0 GHz band is the MSHRS-300X radar sensor, depicted in **Figure 1**, below, and described more fully in Mantissa's April 17, 2014, *ex parte* filing in Dockets 10-28 and 11-90, incorporated herein by this reference.[1] The MSHRS-300X device is a millimeter wave miniature radar sensor, the size and weight of a compact camera, designed for perimeter security applications. The sensors are highly effective for the purpose of detecting the presence of people at locations where they are not supposed to be, for example approaching or climbing over border fences around critical infrastructure. As such, they are extremely well suited for a host of homeland and commercial security applications, including monitoring of boundaries along critical infrastructures, such as railroad lines, pipelines, and airports, and protection of facilities such as power plants, water treatment plants, transit stations, storage depots, military installations, correctional institutions, and government buildings. They can also serve as efficient detection means for low-altitude flying miniature drones. The Mantissa radar sensors are short range, low power, low cost, and can be arrayed to provide continuous, cost-effective security coverage around the entirety of a perimeter. The MSHRS-300X can be precisely mounted and aimed, avoiding interference with vehicle-mounted radar systems on adjacent roadways and other allowed uses of the applicable spectrum band.

Figure 1

[1] Letter from Mantissa Ltd. to Secretary Dortch, dated April 17, 2014: http://apps.fcc.gov/ecfs/comment/view?id=6017612238

Technical Specifications

While there are many types of radar, the MSHRS-300X radar is technologically very similar to the small, vehicle-mounted radar devices already approved for use in the 76.0-77.0 GHz band and present in many of today's automobiles. The Mantissa device emits a beam of low energy electromagnetic radiation in a 100-200 MHz sub-band between 76.0 and 77.0 GHz. The current device operates between 76.0 and 77.0 GHz, but the entire 76.0-81.0 GHz band is suitable for such devices. Physical objects in front of the radar and within its fixed receiving antenna beam reflect back a fraction of the impinging energy, and in this way are accurately detected and measured. The measured physical quantities are time delay, frequency shift (Doppler), and signal intensity. Using these measurements, exact range, velocity and angle of the detected persons or objects can be determined, accurately located, and tracked. A DSP (digital signal processor) inside the radar then builds a map of the locations and parameters of the detected persons or other objects, and further analyzes which of these detections are in restricted or banned areas. The small size and low weight of the sensors, made possible due to the high frequency used, enable concealment when installed, which is a desirable feature in security applications.

To fully cover a perimeter, several of these radar sensors may be connected in a network. The network utilizes an RS-485 or IP protocols and connects to a central command and control center. At the command and control center, tracks that are reported by the networked sensors are presented over a unified display, providing the operator with a clear picture of the area to be protected and any possible security breaches.[2]

The sensor applies advanced signal processing algorithms that exploit the fine range and Doppler resolution of millimeter waves to accurately track persons or objects of interest and distinguish between them and nuisance detections. Mantissa's agile waveform change capabilities and advanced signal processing techniques make it possible to operate in harmony with other radar sensors in the 76.0-81.0 GHz frequency band by quickly switching frequencies when needed, while maintaining full operational functionality.

[2] The transmitted wave form is FMCW, with up and down chirps. Being digitally controlled, all waveform parameters such as sweep time, frequency bandwidth, PRF (pulse repetition frequency), number of sweeps, start/stop frequencies and others, can be programmed and swiftly changed according to operational and algorithmic needs.

Specific Technical Advantages of the Mantissa Radar Sensors

Staring antenna. Mantissa's MSHRS-300X is a staring-antenna radar sensor. Radar sensors with staring antennas can be easily installed and positioned such that the beam of the antenna illuminates a pre-defined selected area, optimized towards maximum functionality under the constraint of minimal interference with other nearby radiators. For fixed radar applications, like the MSHRS-300X, this feature coordinates well with spatial mitigation methods to address potential interference.[3]

Agile chirp processing. The MSHRS-300X implements an all-digital waveform synthesis and signal processing. It can adapt immediately (on a sweep by sweep basis) to developing real time situations, in order to maintain concurrently full functionality as well as eliminate any interference (if it occurs) with other devices sharing the 76.0-81.0 GHz spectrum band. Specifically, by multiple concurrent FFTs (Fast Fourier Transforms) that the sensor's internal processor is computing on each transmit-receive batch, any abnormal disturbance can be detected, and if necessary a hop to a different frequency sub-band can be immediately made, within a few milliseconds, prior to the following transmit cycle. Thus, any potential interference is readily avoided.

Off road installation. In its intended applications, the MSHRS-300X would typically be installed at a distance from roadways; therefore, because propagation of electromagnetic waves at 76.0-81.0 GHz is physically confined to relatively short distances and only line-of-sight (ray) propagation, interference with vehicle-mounted radars is highly unlikely. Moreover, even at locations where roads approach a secured zone or run parallel to a secured fence, the fixed security radar devices are typically installed at a much higher position than that of vehicle-mounted radars (*e.g.*, at the top of a fence), in a way that the fixed antenna beams are directed away from the road, such that interference with vehicle radars is avoided. Interference with

[3] Staring antenna systems like the MSHRS-300X, and most of the automotive radar sensors, have relatively wide antenna beams. One of the benefits of using staring antennas is that the EIRP is usually less than that of scanning antennas. The MSHRS-300X has a 12 degrees azimuth by 5 degrees elevation beam width antenna with 24 dBi gain. The device's maximum transmission power is 8 dBm, which totals to 32 dBm EIRP. This figure is comparable to that of the automotive radar sensors and is much less than that of some systems licensed to operate in airports for foreign object debris (FOD) detection.

radio astronomy observatories also is not an issue, because their antennas are aimed upwards to the skies, while the fixed installation and antenna orientation of the MSHRS-300X devices can always be aimed to a noninterfering direction.

Fixed Radar Serves Important, Currently Unmet Security Needs

The Mantissa radar sensors provide a highly reliable, low cost detection system that can complement or even replace ubiquitous video cameras. Unlike cameras, millimeter wave radar sensors enable detection regardless of weather or lighting conditions (day and night are the same to the radar sensors), and they can be arrayed to follow an irregular perimeter, irrespective of features such as curves, turns, hills, creeks, etc. Radar sensors operating in the 76.0-81.0 GHz millimeter wave band are especially useful for security applications because of the fine resolution they provide, which is vital for distinguishing between stationery and moving objects, and between nuisance objects and people. Radars are significantly less susceptible than other perimeter security measures to "false positives," increasing their utility.

Again, the sensors are highly effective for the purpose of detecting the presence of people and objects at locations where they are not supposed to be, for example people approaching or climbing over border fences, drones crossing over critical infrastructure perimeters, etc. Therefore, the sensors are extremely well suited for a host of homeland and commercial security applications, including monitoring of boundaries along railroad lines, pipelines, and airports, and protection of facilities such as power plants, water treatment plants, transit stations, storage depots, military installations, correctional institutions, and government buildings. Recent examples in which radar sensors could have provided superior security abound. For example, perimeter radar can readily detect, and therefore prevent, airport security breaches.[4] The need

[4] Consider, for instance, the five recent security breaches at San Jose's Airport that, among other things, allowed a boy to stow away on a flight to Hawaii. "It appears that this teenager scaled a section of our perimeter," Mineta San Jose International Airport spokeswoman Rosemary Barnes told CNN. The boy "was able to proceed onto our ramp under cover of darkness and enter the wheel well of an aircraft." http://edition.cnn.com/2014/04/21/us/hawaii-plane-stowaway/ The most recent incident occurred this month: http://www.mercurynews.com/crime-courts/ci_27825905/san-jose-airport-suffers-fifth-security-breach-less "For the fifth time in less than a year, a person was arrested after trespassing on airport property at Mineta San Jose International Airport…. Police investigators believe the woman may have scaled the fence near the southwest corner of the airport." "We are vulnerable if people are able to breach the airport's security perimeter and then we have to wait for human contact to stop them," [Rep. Eric] Swalwell said. "There's no electronic way that is alerting airport officials at the moment of the

for cost-efficient airport perimeter security measures was raised in the March 2015 hearings on the Transportation Safety Administration's budget, at which TSA Acting Administrator Carraway testified that the cost is a major concern for many airports.[5] Mantissa's millimeter wave fixed radar sensors offer a low-cost, highly effective solution for such applications.

Fixed radar could have detected and enabled a timely response to other prominent perimeter security breaches, including the August 2012 breach of the Oak Ridge nuclear facility in Tennessee,[6] and the April 2013 attack on San Jose's electric grid.[7] Fixed radar operating in the millimeter wave bands also presents a viable solution to the vexing problem of detecting rogue drones, such as the small drone that landed on the White House lawn recently, which traditional, large-scale radar is ill-suited to detect.[8]

Figure 2, below, is a generic diagram of a typical critical infrastructure protection array using a combined network of Mantissa's millimeter wave radar sensors and traditional security cameras.

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breach. Now, we have to be either lucky or good. So far we are neither." http://www.sfgate.com/bayarea/article/Another-security-breach-at-San-Jose-airport-6172694.php

[5] U.S. House of Representatives, Committee on Appropriations, March 19, 2015 Budget Hearing – Transportation Security Administration, webcast at 1:28: http://appropriations.house.gov/calendar/eventsingle.aspx?EventID=394054.

[6] "The U.S. government's only facility for handling, processing and storing weapons-grade uranium has been temporarily shut after anti-nuclear activists, including an 82-year-old nun, breached security fences, government officials said on Thursday." http://www.reuters.com/article/2012/08/02/us-usa-securtity-nuclear-idUSBRE8711LG20120802

[7] "Around 1:00 AM on April 16, at least one individual (possibly two) entered two different manholes at the PG&E Metcalf power substation, southeast of San Jose, and cut fiber cables in the area around the substation. That knocked out some local 911 services, landline service to the substation, and cell phone service in the area, a senior U.S. intelligence official told Foreign Policy. The intruder(s) then fired more than 100 rounds from what two officials described as a high-powered rifle at several transformers in the facility. Ten transformers were damaged in one area of the facility, and three transformer banks — or groups of transformers — were hit in another, according to a PG&E spokesman." http://foreignpolicy.com/2013/12/27/military-style-raid-on-california-power-station-spooks-u-s/

[8] *See*, http://www.nytimes.com/2015/01/27/us/white-house-drone.html?_r=0

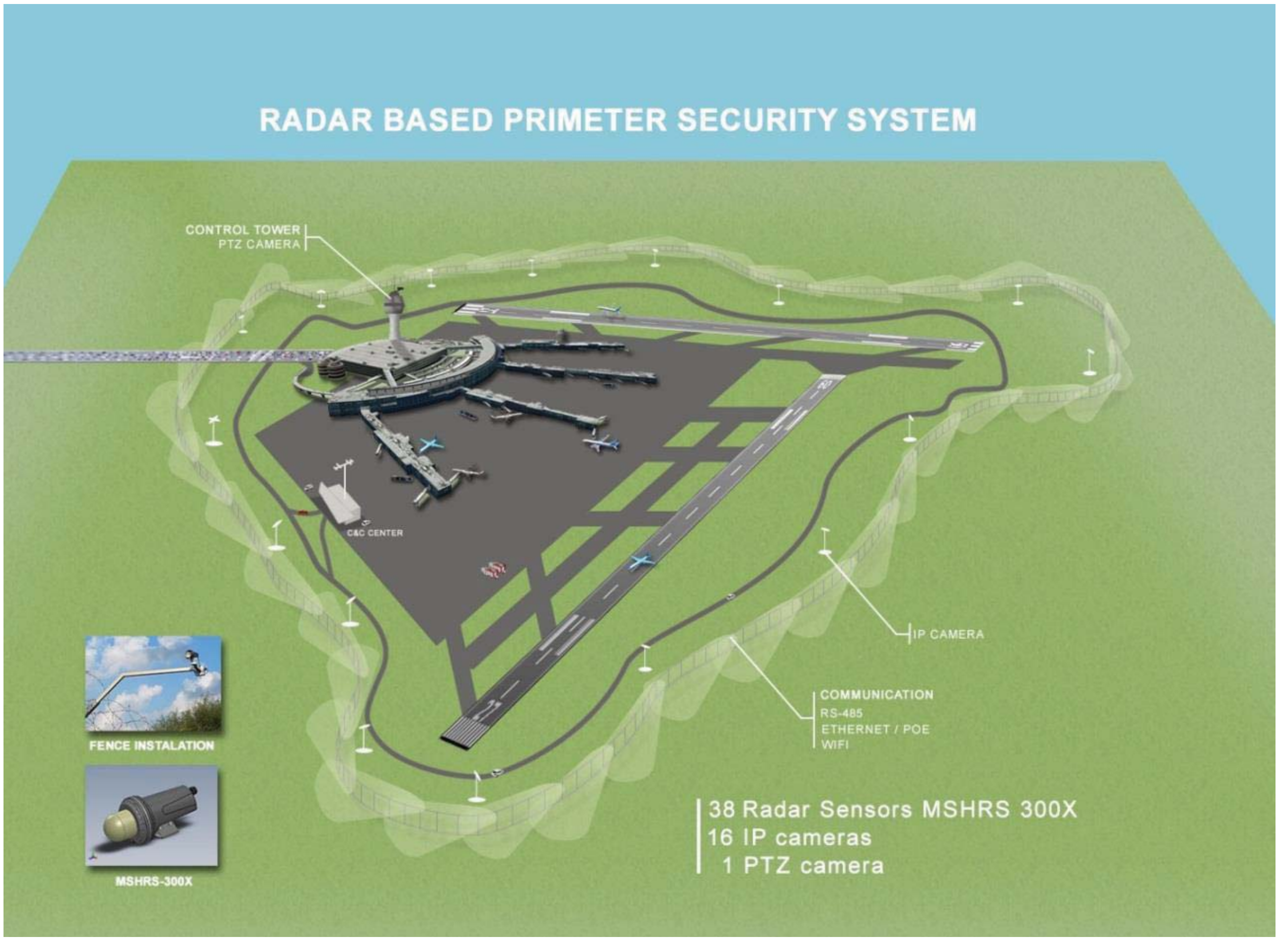

Figure 2

<u>Interference Between Vehicular Radar and Fixed Radar, and With Other Uses of the 76-81 GHz Band, Should Not Be a Concern</u>

The Commission recognizes that millimeter wave devices operating in the 76.0-81.0 GHz band are characterized by their limited range, and therefore present the opportunity for spectrum reuse within quite short distances. "At these frequencies, radio propagation decreases more rapidly with distance than at lower frequencies and antennas that can narrowly focus transmitted energy are practical and of modest size. While the limited range of such transmissions might be a disadvantage for many applications, it does allow frequency reuse within very short distances and thereby enables a higher concentration of transmitters in a geographical area than is possible at lower frequencies."[9] Because of the propagation attributes of millimeter wave spectrum, device interference is less problematic, and more easily managed, than at lower frequencies. It is precisely for this reason that this band is being used to enable potentially millions of radar sensors in automobiles traveling in close proximity to one another on the nation's roads and highways.

Vehicular Radar Compatibility

Despite the unique utility of the 76.0-81.0 GHz band for radar devices in close proximity, comments in the Commission's prior proceedings[10] have noted concerns regarding potential interference between vehicle-mounted and fixed radar systems, and have cited to the interference study conducted by MOSARIM – a European Community funded consortium of automobile manufacturers and others with an interest in vehicular radar systems.[11] Although the MOSARIM study focused on interference among vehicle-mounted radar sensors, it has been cited for the proposition that fixed radar and vehicular radar could interfere with each other. Mantissa has familiarized itself with this study, which identified both a number of potential interference issues and practical, effective mitigation measures to resolve them. Extensive studies, including the MOSARIM study, have clearly shown, that "…vehicular radar sensors are able to share the available frequency spectrum with a variety of other services."[12] In practice, the unlikely radar-to-radar interference is limited only to devices in very close proximity, and is an issue for a range of no more than 50 meters (150 feet) from the device, at most, as is depicted in Figure 19 of the MOSARIM Final Report.[13]

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[9] Notice of Proposed Rulemaking and Reconsideration Order, FCC 15-16, rel. February 5, 2015, in ET Docket No. 15-26, at ¶ 4 (footnotes omitted).

[10] *See*, ET Docket Nos. 10-28 and 11-90.

[11] *See*, MOSARIM Project Final Report, dated December 21, 2012 (MOSARIM Final Report): http://cordis.europa.eu/docs/projects/cnect/1/248231/080/deliverables/001-D611finalreportfinal.pdf
Last accessed April 2, 2015.

[12] MOSARIM Deliverable 1.7 – "Estimation of interference risk from incumbent frequency users and services," at p. 57-58:
https://assrv1.haw-aw.de/index.php/dataexchange/func-startdown/586/
Last accessed April 2, 2015.

[13] MOSARIM Final Report, at page 15.

Figure 6 to the MOSARIM Final Report, below, illustrates some of the numerous scenarios in which vehicular radar devices can interfere with each other. Unlike these scenarios, fixed radar used for security applications will most often be deployed in relatively remote locations, away from traveled roadways.

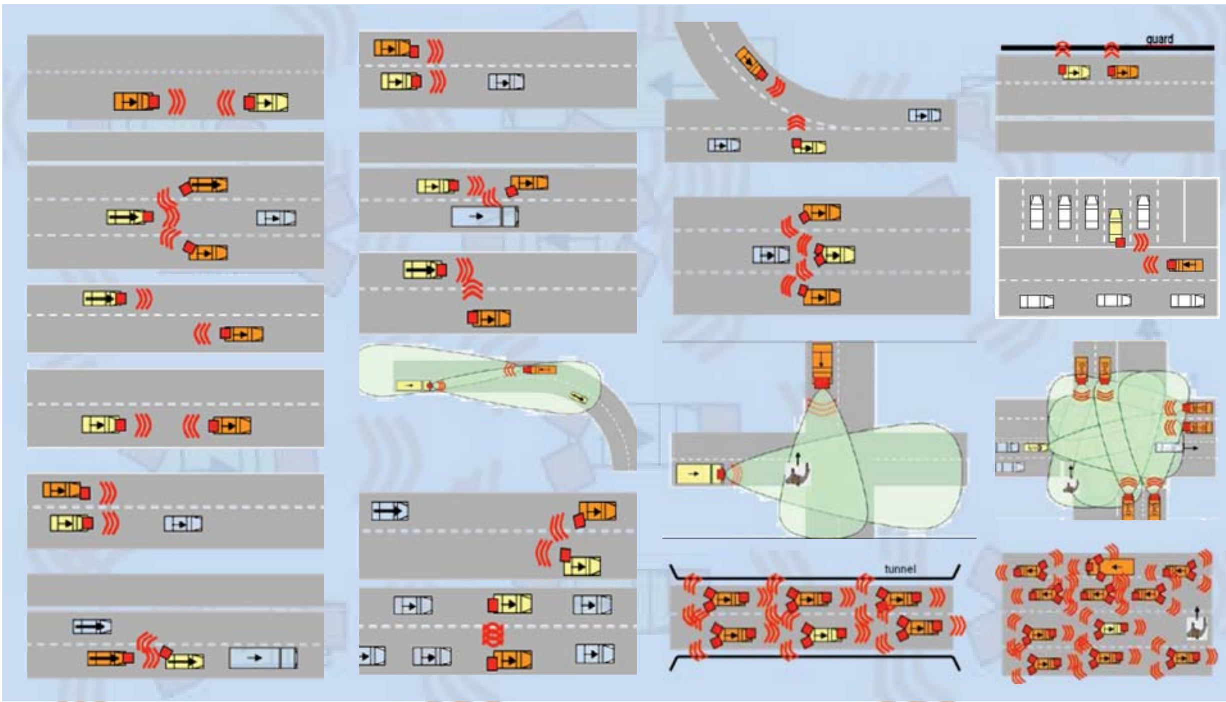

Figure 6: Some scenarios from the catalogue

According to **Figure 17** of the MOSARIM Final Report,[14] there are "9 most promising" techniques for mitigation of radar-to-radar interference:

Ref.	Title	Total ranking from D3.2	Selection Status
T3.1	CFAR (constant false alarm rate) for interference mitigation	470	**Selected techniques for MOSARIM**
T6.5	Detect interference and change transmit frequency range of chirps	463	
T2.1	Using pauses of random length between chirps or pulses	460	
T3.4	Application of driving direction specific pre-defined frequency band separation	437	

[14] MOSARIM Final Report, at page 13, Figure 17.

T6.2	Detect interference and repair Rx results (Time domain)	433	
T2.2	Using random sequence of chirp types (Up-chirp, Down-chirp, CW-Chirp)	432	
T5.4	Digital Beam Forming	425	
T6.4	Detect interference and change timing of transmit chirp or pulses	423	
T1.2	Specific polarization following the Radar location (frontal, rear, side)	421	

Mantissa's MSHRS-300X sensor can readily implement most of these techniques. Many of these techniques are software-based adjustments done in real time, which pose no special challenge to modern radar systems. Furthermore, the mitigation technique ranked first in the MOSARIM Final Report is the CFAR (constant false alarm rate) detection algorithm. Mantissa notes that this 50-year old mitigation technique is fundamental in radar theory,[15] and is commonly applied in virtually every modern radar system. This might explain, at least in part, why there are no reports in the record of actual malfunctioning of vehicle-mounted radars due to mutual interference among them.

In view of the technological similarity between Mantissa's MSHRS-300X device and vehicle-mounted radar systems, Mantissa can apply the same mitigation techniques identified in the MOSARIM study Final Report to mitigate any potential interference issues. At worst, potential interference between the MSHRS-300X devices and automotive radar sensors is the same as the potential interference among automotive radar systems, which has been successfully addressed. In practice, however, the potential interference between the MSHRS-300X devices and automotive radar sensors should be significantly less than among vehicle-mounted radars, since the MSHRS-300X is intended to be installed primarily off roads, mounted 5 to 10 times higher than typical vehicular radar mounting height, and with a well-defined, relatively narrow, and specifically directed antenna beam width.[16] In addition, as noted above, Mantissa's device

[15] *See, e.g.*, "Receiver systems with constant false alarm rate," Jean Cauchois, US patent number 3,423,682, January 1969.

[16] In comparison to the main lobe to main lobe close and direct illumination which is likely to happen among the vehicle-borne radars themselves, the interference from off road surveillance radars is much less significant.

can immediately hop to a different frequency sub-band if needed, in real time. In this way, any potential interference is readily avoided.

Potential interference in this spectrum band with other potential applications also has been extensively addressed, and the conclusion reached that interference is not a significant impediment to shared use. The 2014 Report of the Electronic Communications Committee of the European Conference of Postal and Telecommunications Administrations,[17] on the impact of surveillance radar for helicopter-borne applications, presents the results of compatibility studies addressing the impact of airborne surveillance radar in the 76.0 to 79.0 GHz frequency range on other radio systems and services.[18] With regard to interference of helicopter-borne radar and vehicular and fixed radar, the report concluded:

> *Vehicular radars*
> The only critical situation is when the helicopter is coming to the mainbeam of the vehicular radar. However, this situation is not expected to cause a problem because
>
> - This happens only when the helicopter is flying at very low altitudes below 30m close to a highway and when the helicopter is landing on a highway;
> - For a helicopter assisting in a road accident the traffic is considered to be stopped, rerouted or be moving slowly. Traffic will be kept at a safe distance from the landing helicopter. The helicopter is also not necessarily landing on the road;
> - Because of the relatively low number of helicopter and because only a small percentage of helicopter operations is performed close to road traffic (only emergency missions) the probability of interference is considered to be low;
> - Both radar types (vehicular and helicopter radar) are likely to use FMCW modulation that mitigates the mutual interference. Here it should be considered that the distance between interferer and victim is assumed to be much larger than in the inter-vehicle situation;
> - <u>The beam and frequency scanning capabilities of both radar types can reduce the intercept probability even further</u>.
>
> *Fixed radars*
> In similar manner to the discussion regarding vehicle radars, a helicopter borne radar would only be expected to cause a problem to a fixed radar if the helicopter was landing in the field of observation of the fixed radar, and then only in that particular direction. A

[17] The European Conference of Postal and Telecommunications Administrations is comprised of forty-eight European countries cooperating in the regulation of radio spectrum.

[18] *See*, ECC Report 222, "The impact of Surveillance Radar equipment operating in the 76 to 79 GHz range for helicopter application on radio systems," approved September 2014: http://www.erodocdb.dk/doks/relation.aspx?docid=2530

> fixed infrastructure radar is expected to operate in the presence of other radars, including vehicle radars.
> One of the main applications of fixed radars is for traffic management and automated incident detection. If a helicopter were attending a traffic incident, then a temporary interruption to automated incident detection surveillance would be acceptable.

ECC Report 222, at page 4 (Emphasis added.)

Also of significance is the Commission's 2014 decision in ET Docket No. 10-23 to enable use of the 75.0-85.0 GHz band for level probing radar (LPR) devices.[19] There, the Commission noted that "even if [FOD and LPR radar] were co-located, at these frequencies, the potential for harmful interference to FOD radars from LPR is extremely unlikely, given the substantial free-space propagation losses and the extremely narrow beamwidths of the FOD radar."[20] The Commission stated further: "As for spectrum sharing between vehicular radars and LPR, we believe that LPR devices will be able to co-exist successfully with vehicular radars because the LPR is installed in a downward-looking position at fixed locations and the main-beam emission limits have been carefully calculated to avoid harmful interference to other radio services. We further find that the extreme propagation losses of radio signals at these frequencies would mitigate any potential harmful interference beyond a very short distance from the LPR device, as noted above."[21]

Radio Astronomy Compatibility

As the Commission is aware, radio astronomy sites are almost exclusively located in isolated areas. The antennas of these observatories are pointed upwards to the sky, such that the interference from fixed, properly positioned radars in the 76.0-81.0 GHz spectrum band should be negligible. Since the propagation range of fixed radar operating in this band is very short, the likelihood of interference with radio astronomy installations is extremely small. In the unlikely

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[19] Report and Order and Order, FCC 14-2, rel. Jan. 14, 2105, in ET Docket Nos. 10-23 and 10-27, at ¶¶ 27-29: "The Commission stated its belief that LPR [level probing radar] operation in the 75-85 GHz band would not adversely affect incumbent authorized users, because this band is currently sparsely used and <u>the propagation losses are significant at these frequencies, making harmful interference unlikely beyond a short distance from the LPR device</u>." (Emphasis added.)

[20] *Id*. (footnote omitted).

[21] *Id*.

event a staring-antenna fixed radar was found to be causing interference, it could easily be repositioned or relocated.

Opening the Entire 76-81 GHz Band to Fixed Radar Would Facilitate Optimal Interference Mitigation, As Well As Future Development of Additional Beneficial Applications

In many applications, where fixed radar is used at facilities that are not immediately adjacent to traveled roadways, potential interference with vehicular radar or any other uses of the spectrum will not be an issue. Where it is an issue, however, one of the most desirable mitigation techniques is rapid change of sub-band frequency.[22] Allowing fixed radar to operate throughout the 76.0-81.0 GHz band would enable fixed radar to better employ this mitigation technique, with greater flexibility in the sub-bands available for interference mitigation.

Enabling use of the entire band for fixed radar also could enable and encourage the development of additional, beneficial applications of highly useful fixed radar technology. Potential applications have been reported on in the scientific and development community, and merit consideration as the Commission considers how best to allocate, and facilitate the sharing of, the millimeter wave bands.[23]

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[22] This mitigation technique is identified favorably in the MOSARIM Final Report. See, MOSARIM Final Report, **Figure 17**.

[23] *See*, for example, the National Academies Press publication "Assessment of Millimeter-Wave and Terahertz Technology for Detection and Identification of Concealed Explosives and Weapons" (2007), authored by the Committee on Assessment of Security Technologies for Transportation, of the National Research Council: http://www.nap.edu/catalog/11826/assessment-of-millimeter-wave-and-terahertz-technology-for-detection-and-identification-of-concealed-explosives-and-weapons.
See also, the paper presented at the EuRad 2014 conference on "Consumer Radar: Opportunities and Challenges," in which the authors opined that:

> Modern semiconductor technology, such as small geometry CMOS, is providing the opportunity to build very small and very low cost single chip radar systems operating at millimeter wave frequencies. Such tiny radar systems open up a vast range of new applications from automotive radar, safety helmet radar, bicycle radar, health monitoring radar, robot guidance radar, micro-UAV surveillance radar, and a host of other applications. Co-operative networks of these tiny radars also constitute an exciting possibility. Considerable progress has been made in designing and building millimeter wave CMOS radar systems and addressing the technology limitations imposed by CMOS.

<u>Conclusion</u>

The proposal set forth in the NPRM for shared use of the 76.0-77.0 GHz spectrum band promises to enable cost-effective fixed radar that can be beneficially deployed to address important, currently unmet commercial and government security needs, with minimal risk of interference to other permitted applications, including vehicular radar and radio astronomy. Accordingly, the rule change as proposed should be approved.

Additionally, the Commission should consider expansion of the rule to permit use of the full 76.0-81.0 GHz spectrum band, to enable greater flexibility in interference mitigation, and further development of beneficial applications of radar in the band.

Respectfully submitted,

s/*L. Elise Dieterich*

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April 6, 2015

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> Automotive radar is one of the current challenges driving innovation in small low cost millimeter radar. Another exciting application of small lightweight high performance radar technology is sensing systems for micro-UAVs. More generally the ready availability of tiny, cheap, adaptive radar systems is likely to open up a whole host of new applications mimicking the recent transformations arising from the availability of tiny and cheap GPS systems. Relentless electronic technology scaling is providing the opportunity to move to higher and higher operating carrier frequencies hence enabling complete radar systems (radio frequency front end circuits, digital signal processing and adaptive array antenna systems) to be integrated onto a single chip. Clever new waveform diversity techniques [footnote omitted] together with innovations in small antenna technology mean highly sophisticated consumer radar systems will become a reality over the next few years.

Proceedings of the 11th European Radar Conference, "Consumer Radar: Opportunities and Challenges," at Abstract and page 1.