ECC Report 267

Coexistence of Wideband Ultra-Low Power Wireless Medical Capsule Endoscopy Application operating in the frequency band 430-440 MHz

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0 EXECUTIVE SUMMARY

This Report has been prepared by the ECC Working Group Spectrum Engineering (WG SE) in order to consider the ETSI System Reference Document TR 103 451 [1], which requested regulatory action to allow spectrum access for a new generation of professional medical Short Range Device (SRD) application termed Ultra-Low Power Wireless Medical Capsule Endoscopy (WMCE) and designed to be operated in UHF range around the 433 MHz.

The WMCE application is designed for professional medical use, to provide a convenient tool for diagnosis and treatment of human gastrointestinal (digestive) tract diseases. Its main benefit compared with endoscopy tools traditionally used for this purpose is to offer an option of non-painful and non-invasive procedure with very low risk of bleeding or other side effects. WMCE application consists of two elements:

- a disposable miniature optical imaging camera implemented in the shape of a capsule - Capsule Camera (CCam), which is swallowed by the patient and transmits imaging data;
- a wearable Data Recorder (DR) placed on the patient to receive and store the imaging data transmitted by CCam.

Based on the analysis presented in this Report, it may be concluded that WMCE and specifically CCam transmitters would not create significant risk of interference to other established users of the band. The analysis uses the Minimum Coupling Loss method.

Moreover, the computations showed that the proposed new application would not be even detected beyond a few meters from the patient undergoing diagnostic procedure. This is due to the combination of the following factors:

- the e.r.p. density of emissions measured outside patient's body (-50 dBm/100 kHz) would be significantly lower than the generally established spurious emissions limit of -36 dBm/100 kHz in the subject band;
- extremely low, compared with many other SRD applications, deployment density of WMCE and strictly limited duration of single-use disposable CCam devices;
- during the procedure, patients would likely spend utmost time indoor, either in hospital or at home. This provides an additional wall shielding.

Regarding the interference in the other direction, there is a marginal risk of interference into DR receivers in case they happen to operate in close proximity to high power stations using the same band, such as Amateur Radio or radiolocation. However, investigations show that up to today, the first generation of CCams very rarely experienced interference. Rare events of data loss are considered acceptable for WMCE, as they are a non-life-critical application. Since the density of both interferers and victims is very low, the probability of interference is extremely low. However, it is up to a manufacturer to implement mitigation techniques such as digital filters to address in-band narrowband interferers.

As overall conclusion, the above findings show a possible designation of the band 430-440 MHz as operating band for Ultra-Low Power WMCE application as feasible.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
C/I	Carrier to Interference ratio
CCam	Capsule Camera, the transmitting part of WMCE application
CEPT	European Conference of Postal and Telecommunications Administrations
CTCSS	Continuous Tone-Coded Squelch System
dB	Decibel
dBm	Decibel relative to 1 mW
DR	Data Recorder, the receiving part of WMCE application
ECC	Electronic Communications Committee
e.r.p.	Effective Radiated Power
ETSI	European Telecommunications Standards Institute
FSK	Frequency-shift keying
GFSK	Gaussian Frequency-shift keying
IARU	International Amateur Radio Union
ISM	Industrial Scientific Medical
Mbps	Mega bit per second
MCL	Minimum Coupling Loss
MSK	Minimum-shift keying
OFDM	Orthogonal frequency-division multiplexing
Pfd	Power flux density
RF	Radio Frequency
RX	Receiver
SRD	Short Range Device
SRdoc	System Reference document
TX	Transmitter
UHF	Ultra-High Frequency
WMCE	Wireless Medical Capsule Endoscopy
WG SE	Working Group Spectrum Engineering

1 INTRODUCTION

This Report has been prepared by the ECC Working Group Spectrum Engineering (WG SE) in order to consider the ETSI System Reference Document TR 103 451 [1], which requested regulatory action to allow spectrum access for a new generation of professional medical Short Range Device (SRD) application termed Ultra-Low Power Wireless Medical Capsule Endoscopy (WMCE) and designed to be operated in UHF range around the 433 MHz. This new SRD application would be a valuable diagnostic tool. It allows performing medical examination of patients with various gastrointestinal conditions without the bleeding or sedation risks entailed by endoscopy. The key part of the new application is a disposable miniature optical imaging camera implemented in the shape of a capsule, hence termed Capsule Camera (CCam). It is swallowed by the patient and transmits imaging data to a Data Recorder (DR) while moving through the patient's digestive system.

Currently, the globally harmonised ISM band covers the frequency band 433.05-434.79 MHz. In the ETSI System Reference document (SRdoc) TR 103 451, however, WMCE applications are defined as operating in the frequency band 430-440MHz with a bandwidth up to 10 MHz.

The System Reference document recommended designating for CCam transmissions the frequency band 430-440 MHz with maximum allowed e.r.p. of -40 dBm, measured outside patient's body. This Report identifies the potentially affected incumbent radio-communication services in the subject band and looks at the compatibility issues involved with such regulatory action.

2 DEFINITIONS

Term	Definition
Ultra-Low Power Wireless Medical Capsule Endoscopy	A Short Range Device application to be used for performing medical observation of human gastrointestinal tract by swallowing a Capsule Camera and receiving obtained images by external dedicated receiver, a Data Recorder
Capsule Camera	Miniature disposable capsule-shaped optical imaging camera with integrated Ultra-Low Power transmitter, a key element of Ultra-Low Power Wireless Medical Capsule Endoscopy Application
Data Recorder	Device worn by a patient in order to record the stream of images received from Capsule Camera and store it until it could be downloaded at the end of diagnostic procedure to doctor's Personal Computer for examination

3 PROPOSED NEW GENERATION OF WMCE APPLICATION

3.1 OPERATIONAL SCENARIO

This section provides a short technical summary of the proposed new generation of the WMCE application as described in ETSI TR 103 451 [1]. The reference may be further consulted for further technical details including market data as usually requested by CEPT ECC.

WMCE application is designed for professional medical use to provide a convenient tool for the diagnosis and treatment of the gastrointestinal tract diseases. Its main benefit compared with traditional endoscopy tools is to offer a non-painful and non-invasive procedure with very low risk of bleeding or other side effects. This is achieved by employing a miniature pill-shaped disposable CCam device and having one or more built-in imaging sensors swallowed by a patient. Then, the CCam is naturally propelled through the patient's digestive system while transmitting internally obtained high resolution optical images through short range wireless connection to DR placed immediately outside patient's body (e.g. belt worn) as illustrated in the following Figure 1.

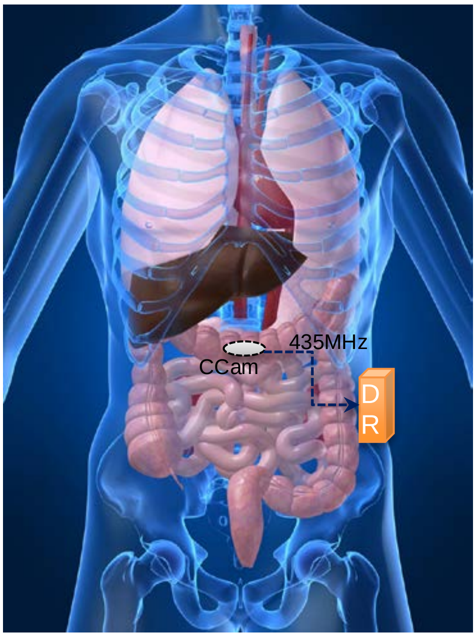

Figure 1: Wireless Medical Capsule Endoscopy application scenario with CCam and DR

The Data Recorder (DR) may include an external antenna (possibly also with some active Radio Frequency (RF) front-end amplifier). It is to be placed directly on the patient's body by means of sticky pads or a designated belt worn around the waist in order to ensure the reliable reception of weak signals from the CCam passing inside the patient's digestive tract.

The CCam should pass through the entire digestive tract within up to 12 hours, by which time its battery will be naturally depleted, and the CCam will become inactive. By that time, the DR will also be removed from the patient's body, and the accumulated imaging data will be transferred through cable interface to some workstation for diagnostic analysis.

The activation and administration of the CCam will always be done by medical staff in closed clinical environments (indoor use). After the ingestion of the capsule, the patient could be allowed to return to his/her house. This implies that in such a case, the patient carrying an active WMCE set could be outdoors for the short time while his/her transfer from hospital to home.

It is therefore very likely that patients would spend most of the procedure time at rest in indoor environments such as at hospital or at home. From a radio-communication perspective, it is therefore correct to assume that a patient's CCam inspection session is utmost an indoor operation.

The above is further supported by the analysis of target medical market for WMCE applications explained by TR 103 451 [1].

3.2 TECHNICAL CHARACTERISTICS

Current forecasts [1] suggest that the deployment density of active CCam transmitters in urban environments would not exceed 0.004 devices/km^2 in the short term, and with long term market saturation a limit is estimated at 0.03 devices/km^2.

The key technical parameters of the CCam RF transmitter, relevant for coexistence analysis, are given in Table 1.

Table 1: Key RF parameters of CCam [1]

Parameter	Value
Operating frequency band	430-440 MHz
Occupied RF bandwidth (99%)	Single channel up to 10 MHz
Max e.r.p. of the CCam TX	-30 dBm
e.r.p. outside patient's body	-40 dBm
Max e.r.p. density outside patient's body (TX mask limit)	-50 dBm/100 kHz (Note 1)
Duty Cycle	Up to 100%
Activity Cycle	Single use, up to 8-12 hours

Note 1: the e.r.p. density limit given here is not to be directly bandwidth-convertible with the total in-channel e.r.p. limit. Please refer to the following paragraphs for more details on this issue.

The e.r.p. values are consistent with ETSI TR 103 451 [1], once the body loss assumption of 10 dB is applied to differentiate the values inside/outside the body. It is to be noted that the last value is referring to power density, i.e. allowing for any unevenness of emissions over a very large channel bandwidth, and is therefore defined on a different, i.e. smaller, reference bandwidth of 100 kHz as opposed to total power defined for 10 MHz channel.

It should be noted that the CCam emissions may not be very uniform across the entire 10 MHz channel bandwidth. Normally the -40 dBm of total power as contained within the 10 MHz channel would correspond to uniform density of -60 dBm when converted to 100 kHz measurement bandwidth. However, 10 dB higher (-50 dBm) TX mask density limit is set over 100 kHz measurement bandwidth to allow for non-uniform emission envelope. Accordingly, for coexistence analysis, the -50 dBm/100 kHz TX mask density value was used as (conservative) reference maximum emission when evaluating its impact to other incumbent users of this band.

As regards spectrum access, it is assumed that CCam transmitters after their activation will employ direct access to radio channel with up to 100% DC to transmit stream of images using digital modulation such as MSK. As indicated in [1], the minimal image size allowing sufficient resolution for medical purposes is 256 rows × 256 columns × 8 bit/pixel = 512 Kbit. Practical tests showed that when CCam moves rapidly through the human gastrointestinal tract up to 20 images per second are required from one image sensor to get an adequate diagnostic coverage. This means that even in minimum resolution scenario the CCam will be generating a raw imaging bit stream of up to ~10 Mbps with one imaging sensor, or up to ~20 Mbps for 2 imaging sensors CCam.

As stated in [1], it was reported that the minimum required bit rate in the uplink channel may be up to ~4 Mbps for CCam with one imaging sensor or up to ~8 Mbps when CCam employs two imaging sensors. If utilising MSK modulation this may result in up to 10 MHz of channel bandwidth.

4 COEXISTENCE ANALYSIS

4.1 INCUMBENT SERVICES IN THE BAND

The target operating frequency band for CCam applications is 430 MHz to 440 MHz. The relevant provisions of ITU Radio Regulations' Article 5 [3] and European Common Allocations (ECA) [4] table are summarised in the following Table 2.

Table 2: Extract of ITU Radio Regulations and ECA for frequency range 430-440 MHz

Frequency Band	ITU RR Allocations	ECA Allocations	ECA Applications
430-432 MHz 5.271, 5.274, 5.275, 5.277 EU12	RADIOLOCATION AMATEUR	RADIOLOCATION AMATEUR	Amateur
432-433.05 MHz 5.138, 5.271, 5.276, 5.277, 5.280 EU12	Earth Exploration-Satellite (active) (5.279A) AMATEUR RADIOLOCATION	AMATEUR Earth Exploration-Satellite (active) (5.279A) RADIOLOCATION	Amateur Active sensors (satellite)
433.05-434.79 MHz 5.138, 5.271, 5.276, 5.277, 5.280 EU12	RADIOLOCATION AMATEUR Earth Exploration-Satellite (active) (5.279A)	RADIOLOCATION Earth Exploration-Satellite (active) (5.279A) Land Mobile AMATEUR	Active sensors (satellite) Non-specific SRD Amateur ISM
434.79-438 MHz 5.138, 5.271, 5.276, 5.277, 5.280, 5.282 EU12	AMATEUR Earth Exploration-Satellite (active) (5.279A) RADIOLOCATION	AMATEUR-SATELLITE Earth Exploration-Satellite (active) (5.279A) AMATEUR RADIOLOCATION	Amateur-satellite Active sensors (satellite) Amateur
438-440 MHz 5.271, 5.274, 5.275, 5.276, 5.277, 5.283 EU12	RADIOLOCATION AMATEUR	RADIOLOCATION AMATEUR	Amateur

Based on the above summary of current ITU Radio Regulations and European common frequency allocations and use, it may be seen that the proposed use of Wideband Ultra-Low Power Wireless Medical Capsule Endoscopy application operating in the frequency band 430-440 MHz would mean band sharing with the following typical European radio-communication applications:

- Amateur Service;
- Earth Exploration-Satellite Service (active sensors);
- Non-specific SRD;
- Radiolocation.

There are known some installations of powerful radiolocation stations in at least two European countries, and they utilise primary service allocation in this band. The powerful signals from any such radiolocation stations may cause disruptions to the communication of very weak signals from CCam to DR. In the following sections, a review of the band sharing prospects with each of potentially affected applications is made.

It was also brought to the attention of this study that WMCE applications may occasionally suffer from unwanted emissions in cases of physical proximity to high power users of adjacent bands such as short-wave radio-communication stations or TETRA base stations. However, as any such cases of adjacent band interference, the impact would be limited to the areas immediately adjacent to interfering stations. Evaluating any such residual risk from unwanted out-of-band emissions of services in adjacent bands would be entirely up to the manufacturers of WMCE equipment whom have to deal with such interference without requiring protection.

4.2 SHARING WITH AMATEUR SERVICE

As regards sharing between the proposed WMCE application and the Amateur and Amateur-Satellite services, it should be noted that the Recommendation ITU-R M.1044 [2] recommends that that the Amateur and Amateur-Satellite services may readily share with, inter alia, the Land Mobile services where traffic density is low.

Given that by their essence of operation at unidentified/changing locations the SRD applications such as WMCE are akin to mobile services and noting that in this case the CCam deployment and use density would be extremely low, and further shielded by buildings given highly unlikely occurrence of operating these two very different services in the same localities, the provisions of this ITU-R Recommendation may be understood to implicitly endorse the sharing between the amateur/amateur-satellite services and the proposed WMCE application without requiring any further quantitative investigation.

In the course of this study, the International Amateur Radio Union (IARU) agreed with the above conclusion regarding interference to the Amateur Service from the CCam. However, the IARU also expressed opinion that some consideration needs to be given to the possibility of interference in the other direction. It could be i.e. to the DR receivers from stations in the Amateur Service but also, in certain geographical areas, from Radiolocation Service and Land Mobile Radio. The following band usage information and corresponding coexistence analysis address this issue.

Radio Amateur Transmissions existing in the band 430 to 440 MHz

- Propagation beacons
  - Within the CEPT, there are 105 beacon transmitters operating on various frequencies between 431.999 MHz and 432.990 MHz, with e.r.p. ranging from 0.1 to 600 watts. These operate on a 100% duty cycle. The average e.r.p. from published information would appear to be about 25 watts, but with a very wide spread.
- Repeaters – Analogue and digital
  - In the UK alone, there are 320 repeaters with a wide geographical spread and e.r.p. of 25 watts, 64 repeaters linked to the internet and over 200 digital repeaters, and the numbers are growing. Because of interlinking, transmit duty cycles for the digital repeaters can reach levels as high as 80% during the day. Older analogue voice repeaters, even when not in active use, transmit information such as its call sign, location and often the CTCSS tone designation required for access at regular intervals between 5 and 15 minutes.
- Other Amateur use
  - Mobile stations with an e.r.p. of 50 watts can appear in a random manner: similarly fixed stations with an e.r.p. of 100 watts or more are not uncommon. Infrequently at weekends, there are competitions in which well-sited portable stations can be found using an e.r.p. up to 40kW from the use of high gain antennas.
- Non-Amateur Land Mobile Radio in the London area also uses frequencies in the band 430-432 MHz, and consideration needs to be given to the possibilities of interference from this service.

Co-existence of existing narrowband CCam operations with Radio Amateur use:

First generation of capsule endoscope devices operating at 433.92 MHz and using MSK modulation have been on the market for more than ten years, albeit with a narrower bandwidth than is proposed in the ETSI TR 103 451 [1]. So far, the vendors and users of those early CCam versions did not report any significant problems related to interference from other users of the band. It is to be noted that there was a complete session of five papers on the first generation of Capsule Endoscopy at the Conference on Electronics in Medicine and Biology held in Lyons, France, in August 2007.

However, it is difficult to draw a conclusion from the performance achieved from existing capsule endoscopes operating at 433 MHz with respect to interference from the Amateur Services. This is because the receiver bandwidth is less than 10 MHz, and so many of the transmissions in the Amateur Service, which might cause interference, are on frequencies outside the receiver bandwidth. This is no longer the case with a receiver having a 10MHz bandwidth, and any signal can be considered a potential interferer.

Analysis for DR as a victim

As shown in Table 1, the CCam's e.r.p. outside the body will be -40dBm. The modulation to be used is not specified, but limitations in power and size suggests that for a 4Mbps data rate FSK, GFSK, GMSK or OFDM will be necessary. Assuming the minimum required C/I is 10dB (achievable with coherent detection), this means a maximum interfering signal level of -50 dBm for one interferer with a minimum coupling loss from a 25 watt signal of 94 dB:

$$20 \cdot log\left(\frac{4\pi f[MHz] \cdot 10^6}{c[\frac{m}{s}]}\right) + \alpha \cdot 10 \cdot log(d[m]) \geq 94\ dB$$

Applying a simplified version of the free space path loss model (just taking into account the coefficient for the distance) from Recommendation ITU-R P.525 [9] and Recommendation ITU-R P.1411 [10], this equates to a free space interfering range of less than 2.8 km and when using the urban path loss model with a coefficient α of 3.5, an interfering range of 93 m.

There is an inherent assumption in above calculation that only one possible interferer exists which may well not be the case. The rare case of 4 nearby interferers of equal strengths may be described by the following expression:

$$20 \cdot log\left(\frac{4\pi f[MHz] \cdot 10^6}{c[\frac{m}{s}]}\right) + \alpha \cdot 10 \cdot log(d[m]) \geq 100\ dB$$

This equates to interfering range of 5.6 km if assuming free space path loss and 138 m for the urban path loss model.

It should be noted that both beacons and repeaters are generally situated in elevated locations and can thus have a propagation coefficient α greater than 2 but less than the 3.5 used for true urban propagation prediction.

In conclusion, it is not possible to establish a definite probability of interference free operation because of the possible variations in radiated power and propagation. At the same time, it should be seen in the context of overall very low density of both WMCE use instances and Radio Amateur stations which makes their co-location in time and geographical locality a highly rare occurrence. Therefore, it may be reasonably asserted that the majority of WMCE users will not experience problems, although allowing uncontrolled ambulatory activity could lead to data loss in some rare situations. However, given that WMCE application is used solely for diagnostic purposes in non-real-time circumstances, any occasional data loss would just require repetition of the WMCE diagnostic procedure, perhaps in more controlled hospital environment if there is a suspicion that patient's home may be located near interference source that precludes reliable transfer of information between CCam and DR.

4.3 SHARING WITH EARTH-EXPLORATION SATELLITE SERVICE (EESS) ACTIVE SENSORS

In accordance with the ITU RR footnote 5.279A, the active space-borne sensors (Synthetic Aperture Radars) within the Earth-Exploration Satellite (active) service may be used in accordance with provisions of Recommendation ITU-R RS.1260 on "Feasibility of sharing between active space-borne sensors and other services in the range 420-470 MHz" [5][3].

In order to safeguard operation of many other radio-communication services utilising frequency range 420-470 MHz this recommendation establishes that the Synthetic Aperture Radars may be operated only in short-term, infrequent and geographically targeted campaigns. This is in compliance with certain pfd limits established at the surface of the Earth and around certain more sensitive installations of, for instance, wind profiling radars.

It may be therefore reasonably assumed that the above provisions would also ensure implicit compatibility of active space-borne sensors with the proposed WMCE application, given its Ultra-Low Power emissions and especially thanks to additional mutual shielding provided by the buildings due to normal indoor location of patients with active CCams during diagnostic procedure.

4.4 SHARING WITH NON-SPECIFIC SHORT RANGE DEVICES (SRD)

According to CEPT ECC Recommendation ERC/REC 70-03 [6], non-specific Short Range Devices (SRD) is allowed to operate in the frequency band 433.05-434.79 MHz. The following Table 3 summarises the key parameters of such Non-specific SRD if they were considered spectrum sharing partners as potential victims of interference from CCam emissions.

Table 3: Parameters of considered victim Non-specific SRD receiver

Parameter	Value
Operating frequency band	433.05-434.79 MHz
Channel bandwidth	25 kHz
Typical antenna gain	-2.85 dBi
Receiver sensitivity	-112 dBm/25 kHz
Target operational margin of wanted signal	10 dB
C/I objective	8 dB

Using these key technical RF parameters of potential victim application vis-à-vis key CCam interfering transmitter parameters shown in Table 1, the coexistence with WMCE could be verified by applying Minimum Coupling Loss (MCL) calculation of minimal separation distance, as shown in the following Table 4.

Table 4: MCL calculation of minimal separation distance from CCam to Non-specific SRD victim receiver

Parameter	#	Value	Remarks
Frequency, GHz	A	0.43	
Interfering power, ERP, dBm	B	-50	
Reference bandwidth associated to "B" above, kHz	C	100	
Victim RX bandwidth, kHz	D	25	
Victim RX antenna gain, dBi	E	-2,85	
Victim RX sensitivity, dBm	F	-112	

Parameter	#	Value	Remarks
Victim RX wanted signal margin, dB	G	10	
Victim RX C/I objective, dB	H	8	
Victim RX interference threshold, dBm	I	-110	I=F+G-H
Bandwidth correction factor, dB	J	-6	J=10*LOG10(D/C)
Minimum Coupling Loss value, dB	MCL	53.3	MCL=B+2.15+J+E-I
Minimal separation distance, m (urban, non-Line of Sight conditions)	Rnlos	6	Rnlos=POWER(10;(MCL-32.5-20*LOG10(A))/35)
Minimal separation distance, m (free space loss, Line of Sight conditions)	Rlos	25	Rlos=POWER(10;(MCL-32.5-20*LOG10(A))/20)

The methodology used in the above calculations is the standard Minimum Coupling Loss (MCL). It consists of determining the basic minimum propagation loss required to avoid interference. Once this value is derived, it is straightforward to derive a corresponding minimum separation distance based on a given propagation model. The propagation model used for the assessment of the separation distance is free space.

Assuming free space propagation (line of sight between the interferer and the victim), the theoretically Minimal separation distance would be 25m. If propagation in an urban scenario is considered (propagation exponent 3.5), the range is reduced to 6 m, if the victim receiver is assumed to be operating at its receiving threshold. In reality, most often victim receivers will operate above their sensitivity threshold and this would further reduce the impact rage of the WMCE interferer.

Considering these maximum realistic/theoretical impact ranges, it may be concluded that interference could only be possible if both WMCE and victim SRD are used essentially in the direct proximity such as within the same or adjacent room.

In the case the patient remained in the hospital during the procedures, the hospital administration could take measures to prevent the simultaneous use of the WMCE and other 443 MHz SRD in the same premises.

Therefore based on above considerations it may be finally concluded that operation of CCam would pose a negligible risk of interference to non-specific SRD in the band.

4.5 SHARING WITH THE RADIOLOCATION SERVICE

Table 5 lists technical parameters of radiolocation stations, which correspond to the data used in ECC Report 240 [7] and provided in the Recommendation ITU-R M.1462 [8].

Table 5: Parameters of radiolocation stations in the band 420-450 MHz

Parameters	Type of radiolocation station	
	Airborne	Ground
Bandwidth, MHz	1	1
Noise floor, dBm	-108.9	-109.9
Protection Criterion: I/N, dB	-6	- 6
Maximum Tolerable Interference, dBm	-114.9	-115.9
Antenna Gain within main lobe, dBi	22	38
Radar height above ground level, m	> 9000	8
Polarisation	Circular	Circular

Table 6 shows the distances of CCam from a victim radiolocation station obtained using the MCL method.

Table 6: MCL calculation of minimal separation distance from CCam to Radiolocation stations

Parameter	#	Value for airborne radar	Value for ground radar	Remarks
Frequency, GHz	A	0.43	0.43	
Interfering power, ERP, dBm	B	-50	-50	
Reference bandwidth associated to "B" above, kHz	C	100	100	
Victim RX bandwidth, kHz	D	1000	1000	
Victim RX antenna gain, dBi	E	22	18	For ground based radar, an average side-lobe attenuation of 20 dB is considered.
Victim RX interference threshold, dBm	I	-114.9	-115.9	
Bandwidth correction factor, dB	J	10	10	J=10*LOG10(D/C)
Minimum Coupling Loss value, dB	MCL	99.05	96.05	MCL=B+2.15+J+E-I
Minimal separation distance, m (urban, non-Line of Sight conditions)	Rnlos	129	105	Rnlos=POWER(10;(MCL-32.5-20*LOG10(A))/35)
Minimal separation distance, m (free space loss, Line of Sight conditions)	Rlos	4943	3460	Rlos=POWER(10;(MCL-32.5-20*LOG10(A))/20)

With regards to airborne radars, the minimal separation distance does not exceed 4.9 km, while the operational altitudes of such radars are normally higher than 9 km. Therefore, interference would not occur in normal operational conditions.

Concerning ground based radars, under the conditions and scenarios described above, the results in Table 6: show a minimal separation distance about 3.4 km. However, considering the low deployment density of active CCam transmitters, it is unlikely that the CCam use would create a high risk of interference.

5 CONCLUSIONS

Based on the analysis presented in this Report, it may be concluded that it is improbable that the proposed use of WMCE application with CCam transmitter would cause significant risk of interferences to other established users of the band.

Moreover, it is unlikely that the proposed new application could be detected beyond a few meters from the patient because of the following factors:

- The e.r.p. density of emissions measured outside patient's body (-50 dBm/100 kHz) would be significantly lower than the generally established spurious emissions limit of -36 dBm/100 kHz in the band;
- Extremely low, compared with many other SRD applications, deployment density of WMCE and strictly limited duration of single-use disposable CCam devices;
- During the procedure, the patients would likely be indoors, either in hospital or at home. Therefore, additional wall attenuation would increase the protection of the other users of this band.

As regards the interference in the other direction, i.e. risk of interference to DR receiver, investigations show that the first generation of CCams very rarely experienced interference from Radio Amateur stations or Radiolocation stations operating in the 430-440 MHz band. Those rare occurrences of data loss were deemed acceptable, the WMCE being non-life-critical application. Since the density of both interferers and victims is very low, the risk of interference is marginal. Moreover, it is up to the manufacturers to implement mitigation techniques such as digitally filtering of in-band narrowband interferers in order to make the DR receiver more robust.

ANNEX 1: LIST OF REFERENCES

[1] ETSI TR 103 451 'System Reference document (SRdoc); Short Range Devices (SRD); Technical characteristics for UHF wideband Ultra-Low Power Wireless Medical Capsule Endoscopy' (2016)
[2] Recommendation ITU-R M.1044-2 'Frequency sharing criteria in the amateur and amateur-satellite services' (June 2003)
[3] ITU Radio Regulations' Article 5: http://life.itu.int/radioclub/rr/art05.htm
[4] ERC Report 25 'The European Table of Frequency Allocations and Applications in the Frequency range 8.3 kHz to 3000 GHz' (ECA Table) (06/2016)
[5] Recommendation ITU-R RS.1260-1 'Feasibility of sharing between active space-borne sensors and other services in the range 420-470 MHz' (May 2003)
[6] CEPT ECC Recommendation ERC/REC 70-03 'Relating to the Use of Short Range Devices (SRD)' (amended February 2017)
[7] ECC Report 240 'Compatibility studies regarding Broadband PPDR and other radio applications in 410-430 MHz and 450-470 MHz and adjacent bands' (September 2015)
[8] Recommendation ITU-R M.1462 'Characteristics of and protection criteria for radars operating in the radiolocation service in the frequency range 420-450 MHz' (05/2000)
[9] Recommendation ITU-R P.525 'Calculation of free-space attenuation' (11/2016)
[10] Recommendation ITU-R P.1411 'Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz'