ECC REPORT 6

Electronic Communications Committee (ECC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

TECHNICAL IMPACT ON EXISTING PRIMARY SERVICES IN THE BAND 2700 – 2900 MHz DUE TO THE PROPOSED INTRODUCTION OF NEW SYSTEMS

Baden, June 2002

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EXECUTIVE SUMMARY

This report was initiated by the proposed use of two new planned mobile telecommunication applications, Digital ENG/OB (Electronic News Gathering/Outside Broadcast; ground-based) and Digital Aeronautical Telemetry (down-link) transmissions, to access and use frequencies in the band 2700-2900 MHz (S-band), allocated on a primary basis to aeronautical radio navigation services (radars) and meteorological radio location.

The report addresses the technical impact of interference from digital ENG/OB and digital Aeronautical Telemetry to ARNS radar systems, without judgement about sharing feasibility. No account has been taken of interference from radar to ENG/OB or aeronautical telemetry applications. The conclusions of the sharing conditions are expressed in terms of calculated required separation distances between stations in ARNS and interfering ENG OB terminals at a given frequency separation and for a range of radar protection criteria. Concerning radar protection, which is crucial with regard to required separation in distance and frequency, proposed amendments to ITU-R Rec. M.1464 indicates more stringent criteria than the existing (I/N= -6 dB).

In addition to theoretical analysis and calculations, the study includes measurements on radars in operation.

For Aeronautical Telemetry, using radio horizon calculations and ignoring over the horizon effects, co-channel separations distances of 400km are required (corresponding to an aeronautical telemetry transmission altitude of around 10 km). Due to the large separation distances, cross border co-ordination would be required.

For digital cordless cameras applications considered in this report (see Annex 3), use will generally be at altitudes less than the 10km quoted for aeronautical telemetry and, consequently, it is expected that co-channel separation distances will be lower. However, an appropriate level of co-ordination (national or international) will still be necessary. It is to be noted that, due to propagation effects, co-channel separation distances may exceed the radio horizon.

The sharing conditions (ENG/OB vs. Radar) are expressed in necessary geographical separation distance which, at a frequency separation of 10-15 MHz, varies between 1.5-80 km dependent on EIRP (0-17 dBW), radar protection (I/N= -6 to –12 dB) and Radar receiver selectivity (High/Low).

A theoretical extrapolation has been included in the report for a single Aeronautical Telemetry interferer, assuming the same characteristics and impact on the operational radar performance as ENG/OB (currently no harmonised ETSI standards available for Aeronautical Telemetry). Based on these assumptions, required separation distances for the modelled Telemetry case (EIRP assumed to be 11.8 dBW for a specific application), at a frequency separation of 10 - 15 MHz, is estimated to 6-40 km.

Concerning potential saturation effects in the radar receiver due to interference from ENG/OB (digital cordless cameras) using the recommended EIRP=0 dBW, the study showed required separation distances between 1-20 km for various saturation levels between –39 dBm to –20 dBm and eventual additional margins (from 0 dB to 15 dB).

By using the example value EIRP=17dBW for ENG/OB (portable links), the study showed required separation distances between 1-120 km for various saturation levels between –39 to –20 dBm.

Finally, it should be noted that the study addresses radars with typical characteristics. Thus, national exemptions from the determined sharing conditions can not be excluded although the radar type used in the tests is widely deployed in Europe and elsewhere.

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1 INTRODUCTION - CURRENT USE OF THE BAND 2700 – 2900 MHz

1.1 Background

The band 2700-2900 MHz is used by radars for both civil and military applications within the Aeronautical Radionavigation Service and the Radiolocation Service (including meteorological radar).

The aim of this report is to study the possibility of the introduction of digital ENG/OB in the band 2700-2900 MHz. This is done by estimating the potential interference from ENG/OB upon radars. Further studies may be needed to assess the other direction of interference (i.e. from radars to ENG/OB).

The report also considers the possible introduction of other systems in this band, specifically aeronautical telemetry. Consideration of the proposed introduction of UMTS in the band 2700 – 2900 MHz is not included in this Report.

In addition, it should be noted that this report does not address the case of military transportable, long range air defence, airborne radars and other military applications.

Further studies should be conducted to assess the possibility of coexistence between radar systems and digital ENG/OB and aeronautical telemetry in other frequency bands, such as 2900-3400 MHz.

This study is based on relevant ITU-R recommendations for propagation, methodology and radar characteristics such as the Recommendations ITU-R P.452-10, M.1461 (2000) and M.1464 (2000). For a co-ordination process on a case by case bases , due to the distances involved, the propagation models for trans-horizon should be used (ITU-R P.452-10 equation 8c) including diffraction, ducting/layer reflection, troposcatter and clutter losses.

1.2 Current allocations in the band 2700 – 2900 MHz

Article S5 of the Radio Regulations allocates the band 2700 - 2900 MHz as follows in Regions 1, 2 and 3:

2 700-2 900	AERONAUTICAL RADIONAVIGATION S5.337 Radiolocation S5.423 S5.424

S5.337 The use of the bands 1 300-1 350 MHz, 2 700-2 900 MHz and 9 000-9 200 MHz by the aeronautical radionavigation service is restricted to ground-based radars and to associated airborne transponders which transmit only on frequencies in these bands and only when actuated by radars operating in the same band.

S5.423 In the band 2 700-2 900 MHz, ground-based radars used for meteorological purposes are authorised to operate on a basis of equality with stations of the aeronautical radionavigation service.

S5.424 *Additional allocation:* in Canada, the band 2 850-2 900 MHz is also allocated to the maritime radionavigation service, on a primary basis, for use by shore-based radars.

2 DESCRIPTION OF CONSIDERED RADAR SYSTEMS IN THE BAND 2700-2900 MHz

In the 2700-2900 MHz range, radars are dedicated to two main types of application for civil use: aeronautical radionavigation and radiolocation for meteorological applications.

For the aeronautical radionavigation service, radars are ground based systems for air traffic control for both civil and military purposes. For the civil application, the deployment of these radars is known. The number of civil systems in use by different administrations varies.

For the radiolocation service, ground based meteorological radars are authorised to operate in the band 2700-2900 MHz. The aim of these radars is to measure and predict precipitation (rain, snow, hail and sleet).

In this report, four types of radar systems are considered covering both air traffic control and meteorological purposes. Details are given in Annex 1.

2.1 Relevant Radar Functionality and Characteristics

2.1.1 Radar transmitters

Radars employed within the aeronautical radionavigation/radiolocation services are in general pulsed Doppler systems, emitting carrier frequency pulses at a repetition rate of approximately 1,000 pulses per second, yielding an unambiguous target range of 150 km. These radars either use short pulse widths (~1µs), or a combination of short and long pulses (1µs and 20-90µs) to give good short and long range performance. After pulse transmission, i.e. during the so-called echo period which lasts to the next pulse transmission, the radar receiver is responsible to acquire, amplify, process and detect echo signals. Their origin is determined by the echo delay in the radial direction (as seen from the radar) and by the antenna main beam pointing in the azimuth (transversal) direction. However, antenna side-lobes can also contribute echo energy reflected from other azimuth directions. Spatial resolution in the azimuth direction is determined by the antenna main-lobe width, typically about 1.5 degrees 3-dB beam-width.

As the echo signal's free-space attenuation increases with 4th power of range, rather high transmit power levels are necessary in order to receive detectable echo strengths to maximum range from all targets, ranging from large airliners to smaller general aviation aircraft, exhibiting back-scatter cross-sections in the order of 1 m^2. These power levels for conventional tube-transmitters (magnetrons, clystrons) are in the order of 500 kW to 1 MW. More recent designs apply pulse compression for achieving a short (1 µs) received pulse width from a considerably longer (50 µs and more) transmitted pulse, at the advantage of reduced transmit power level (some tens of kW, which can be generated using solid-state amplifier arrays).

Modern radars frequently apply the principle of pulse compression, involving the transmission of suitably modulated or encoded "long pulses", and the processing of received echoes in a way so that signal energy is shifted in the time domain. This results in "short pulse" echoes providing the required range resolution and peak power. In this way sufficient energy – the main criterion for a radar's detection capability - can be sent and received per observed target, without needing high peak power as such in conventional "short pulse" systems. This results in more efficient use of the transmitter's average power capability, in less critical signal transport between transmitter and antenna (e.g. danger of wave guide arcing!) and improved Doppler (velocity) resolving capability. Furthermore, the radar's average power may be increased without increasing the pulse repetition frequency (prf), hence obtaining long unambiguous range.

While conventional "short pulse" duration is in the order of 1 µs, corresponding to 150 m radial range resolution, uncompressed "long pulses" can last several tens of microseconds. In order to make the long pulse compressible, some additional information must be modulated or coded onto the long pulse. This information is then, in the receiver's compression filter, utilised for applying different delays to the individual frequency or code elements of the long pulse, resulting in a short and high-amplitude compressed pulse.

2.1.2 Radar receivers

Radar receivers are generally designed as heterodyne receivers, mixing down the echo signal from the RF domain (microwave frequency f_o, here 2700 – 2900 MHz) to an intermediate frequency (IF or f_{IF}, usually some tens of MHz), where amplitude and phase extraction is performed by a coherent detector or base-band mixer circuitry, delivering the so-called video signal, consisting of real (I) and imaginary (Q) part in phase representation.

The received echo signal leaving the antenna is usually fed directly into the first RF-amplifier (low-noise amplifier, LNA), without any filtering. This causes the RF-front-end of such radars to have an RF-bandwidth B_{RF}, in the order of 100 MHz and more. The first filter element can be found only after the LNA, it is responsible for blocking the image frequency (which would otherwise translate to a "negative" IF, and irrecoverably overlay the wanted "positive" IF). This image frequency filter has still some tens of MHz bandwidth and does not really give protection against near side-band receptions. The radar receiver's signal and noise bandwidth is finally determined by the IF filter, whose width $B_{IF} \approx B_{noise} \approx 1$ / pulse width, in practice in the order of 1 MHz. Nevertheless the large RF-bandwidth has to be taken into account concerning possible LNA saturation and non-linear transfer of energy from somewhere in B_{RF} into B_{IF}.

"Matched Filter" Signal Theory

Signal theory helps to get further insight into the characteristics of this pulse compression technique. What happens during pulse compression, i.e. properly shifting the individual frequency components (sine waves) in the time domain by applying a frequency dependent delay, can also be used for generating a (linear) chirp pulse from a short Dirac pulse, whose spectrum contains all frequencies at equal amplitudes, but with phases properly adjusted so, when summing up all those sine waves, to result in only one single peak in the time domain.

This adheres to the concept of the "matched filter" which is reciprocal in a sense that, if the compression can be achieved with a filter whose frequency response H(ω) is the complex conjugate of the signal's spectrum S(ω), the generation of a chirp pulse from a narrow Dirac pulse can be done with a filter with frequency response H*(ω) (the complex conjugate of H(ω)). In the time domain, when a filter with unit impulse response h(t) is suitable for compression, the time-inverted unit impulse response h(-t) can be used for generating the long pulse from a short Dirac pulse.

2.1.3 Radar processing

The key information to be extracted from this signal is to decide on the presence (position) of a wanted (real) target object, which in principle is determined by applying some sort of threshold detection, i.e. to compare the received echo amplitude V with some threshold value V_T, and interpreting the case $V>V_T$ as "target present". This would be an easy task under idealised conditions, which means in the absence of any noise or echoes from other, unwanted targets ("clutter", e.g. from the always present ground via low-elevation antenna sidelobes, or from precipitation particles aloft), and that the wanted echo signal is stable, i.e. the target's back-scatter cross-section doesn't fluctuate. In consequence besides the real, "valid" target detections, also so called "false alarms", that are targets simulated by noise and/or clutter (and/or external interference!) that will be detected and reported to the radar operator. The key quantities for describing detection performance are:

probability of detection, P_d, and
probability of false alarm, P_{fa},
(which is related to the average time between two false alarms, T_{fa}, with $1 / P_{fa} \approx T_{fa} \cdot B_{IF}$).

Also the probability of missing echoes or targets, $P_{miss} = 1 - P_d$ can be used.

The detection of targets in noise by a radar system is a statistical process and is a balance between the probability of a correct detection, Pd, and the probability of a false alarm, Pfa. The probability that a valid target report will be output by the radar for a given false alarm rate depends on the S/N and the number of hits on the target per scan. The S/N is a function of the target size and range and radar parameters such as noise figure and EIRP. Thus for a given target and a given scan, the probability that a valid target report will be produced varies due to the natural fluctuation of the target (due to propagation loss and target aspect changes within the radar beam) and the statistical nature of the process.

For a single target within the coverage, the Pd is defined as the number of valid target reports (target detection) divided by the number of times that the beam illuminates the target. A large number of illuminations (scans) are required for this number to be statistically significant. For a mix of target sizes and aspects (opportunity traffic), the Pd is defined as the number of valid target reports output from the detection process expressed as a percentage of the expected possible number of valid target reports.

Radar detection requirement is specified by aviation authorities to be greater than 80% Pd on a single target with a 1-2 m^2 radar cross section at a false alarm rate of 10^{-6} in free space conditions, i.e. with no clutter. Experience has shown that for a mixed target scenario the detection criteria of 80% on 1-2 m^2 targets results in an average Pd (overall) of greater than 90%. This means that on every scan of the radar antenna, more than 90% of the targets inside the coverage will produce valid target reports. The specific targets producing valid reports will differ between each scan depending on the range, size and orientation of the target from the radar.

Techniques like Moving Target Indication (MTI) or Moving Target Detection (MTD) and echo integration increase the sub-clutter visibility and allow the radar receiver to detect targets whose power level are below the clutter power level.

The balance between detection and false-alarm probabilities is determined by the choice of threshold level V_T. Selecting a low V_T results in good detection probability, however at the cost of an increased false-alarm rate because noise, clutter or interference, alone or in combination can exceed V_T. In practical systems the ratio between wanted signal power (S) and unwanted noise (N) and/or clutter (C) and/or interference (I) power is never constant. It changes with range, with clutter geometry and material properties, as well as with antenna pointing direction. In order not to overload the radar echo processor with too many (false) detections, the so-called Constant-False-Alarm-Rate (CFAR) processor dynamically changes the threshold level to maintain a constant false alarm rate. This is done by evaluating echo levels and phases in the echo cell's boarding cells of interest, and shifting the threshold level V_T to a higher value if intense noise, clutter and/or interference levels are present in that region at instant in time. Applying this strategy keeps P_{fa} more or less constant, but at the same time P_d is reduced as the overall signal-to-noise ratio (S/(N+C+I)) is reduced.

Owners and operators of radars used for operational aeronautical navigation are required to fulfil certain minimum standards imposed by relevant ICAO recommendations and Eurocontrol standards. Actual values are $P_d > 90\%$ with less than 20 false alarms reported per antenna round scan (i.e. 360 ° azimuth rotation), over the total specified acquisition range and with all kind of possible clutter at the specific site. This performance is in practice calibrated by adjusting the CFAR circuitry's threshold offset so that an echo simulator produces $P_d = 90\ \%$ at $P_{fa} = 10^{-6}$ for a single simulated 2 m^2 radar cross section test target.

In practice disturbing effects like noise, clutter and external interference are always present and require some sophistication in the thresholding and detection processes. The key element of modern radar processors is integration in space and time, i.e. to base any detection decision on more than one single echo per target area and to apply coherent detection and phase continuity (Doppler) principles, in order to discriminate between wanted and unwanted echoes. For this purpose arrays of echo cells, centred at the echo cell of interest, taken not only from one single sweep (i.e. antenna azimuth rotation), but from a number of consecutive sweeps, are looked up and statistically evaluated via maximum-likelihood techniques, so to optimally discard echoes generated by band-limited white noise (with Rayleigh amplitude distribution) as well as more slowly fluctuating ground echoes. Such processing and detection schemes are more or less optimised for the two main types of unwanted echoes (band-limited white noise and ground clutter), but not necessarily for external interference with quite different time domain response and amplitude distribution, as will be demonstrated by measurement results presented below.

2.1.4 Theoretical considerations

In theory, sensitivity of P_d on changes in S/N (or combined S/(N+C+I)) lies between 3 and 30 percentage points per dB, depending on the signal statistics (Rayleigh or Ricean amplitude distribution, slow (scan-to-scan) or fast (pulse-to-pulse) fluctuation), the number of echoes integrated, echo components measured and taken into account during processing (amplitude only or both, amplitude and phase), etc.
This applies to original P_d values around 90 %, i.e. when reducing S/N by 1 dB relative to the original value, P_d is expected to be reduced significantly, in keeping P_{fa} constant (as it is done in the practical receiver by CFAR processing). This shows us that in a radar receiver it is worthwhile to gain every possible tenth of a dB signal-to-noise ratio, explaining the absence of selective filter circuits in front of the RF low noise amplifier.

Finally it has to be mentioned that in the RF front-end of a radar receiver, usually just before the low-noise amplifier (or even being a part of it) the so-called STC (Sensitivity Time Control) circuitry is present, the purpose of which is reducing the receiver's gain (or sensitivity) for echoes from nearby targets and ground clutter, which could drive the receiver into saturation. In most cases this STC circuit is implemented as an electronically variable attenuator, which starts at high attenuation immediately after pulse transmission and then reduces its value, reaching 0 dB_{rel} at 15 nmi range typically, corresponding to about 200 µs echo time. Beyond this range, up to next pulse transmission, the receiver works at its full gain and sensitivity.

This is the reason why STC does not play any role in interference calculations. External interference is unsynchronised with the radar's pulse train that causes its occurrence anywhere in the radar echo period. Therefore one must assume that interference will hit the radar receiver in its most sensitive configuration.

3 POTENTIAL USE OF ENG/OB APPLICATIONS CONSIDERED IN THIS STUDY

The frequencies employed for ENG/OB applications vary across Europe, depending on the applications and the national usage. This is summarised in ERC Recommendation 25-10.

The whole range of ENG/OB applications can be found in the ERC Report 38, but the technical parameters are appropriate only for systems based on analogue/FM technology.

However, within the frequency range 2.7-2.9 GHz, new ENG/OB digital equipment being considered to be introduced, which would be based on DVB-T technology as specified in EN 300 744 (COFDM modulation scheme with 8 MHz channels).

For ENG/OB applications using DVB-T technology, frequency bands up to 4 GHz are necessary for cordless cameras, mobile and portable links and are preferred for typical temporary point-to-point links. Some details are given in Annex 3, as well as some parameters and assumptions necessary for the conduction of compatibility studies.

4 AERONAUTICAL TELEMETRY

Civil and military airborne telemetry applications are currently operated in a number of CEPT countries in the frequency band 1474-1481.5 MHz. Furthermore, in accordance with the ERC Recommendation 62-02, the European Common Allocations table in the ERC Report 25 indicates that parts of the band 2300-2400 MHz are used for aeronautical telemetry on a national basis.

For aeronautical telemetry applications considered in this report, the direction of the link is air-to-ground with airborne transmitters up to a height of 10000 m. This kind of application is expected for tests of on aircraft where the route to be taken by the aircraft is predetermined and the location of the receivers on the ground is known.

The following assumptions are made in this study concerning aeronautical telemetry:

- use of digital technology based on a COFDM modulation scheme;
- channel bandwidth of 5 MHz;
- output power of 15 W (11.8 dBW) with 0 dBi gain omni-directional antennas;
- line-of-sight propagation.

5 DESCRIPTION OF INTERFERENCE MECHANISMS IMPACTING RADARS

There are two mechanisms via which interference may degrade the performance of a radar receiver, described in the following sections.

5.1 IF-band interference

That is interference at a frequency falling into the radar receiver's IF-bandwidth. It directly proceeds through the receiver chain down to the processing and detection section, acting as additional noise and/or clutter (i.e. reducing S/N) and thereby degrading probability of detection P_d and/or false-alarm rate P_{fa} (Desensitisation). In addition, such interference degrades target azimuth determination accuracy, by disturbing any beam centroiding algorithm.

The detection probability degradation is caused by interference signals inside the radar receiver’s bandwidth (IF bandwidth). But also signals originally outside this bandwidth may be transferred into it due to 3rd-order intermodulation. For this mechanism to become effective, two interference signals ("tones") at frequencies f_1 and f_2 must be present, which fulfil the condition $f_2 – f_1 = f_1 - f_o$, with f_o being the radar centre frequency. In practice interference signals are not narrow tones but broadband, so that it is quite probable that part of the interference signal energy matches the stated conditions and translates into the IF-bandwidth.

Furthermore, interference in the vicinity of the radar’s image frequency ($f_{image} = 2f_{local\text{-}oscillator} – f_o$) can, due to non-infinite attenuation of the image rejection filter, directly enter the receiver via the IF-bandwidth and consequently degrade P_d. This effect can lead to an increase of the necessary distance separation in the vicinity of the radar’s image frequency.

5.2 RF-band interference

That is interference outside the radar receiver's IF-bandwidth, but inside its wider RF-bandwidth. It can:

- overload the receiver front-end, causing saturation and desensitisation for useful signals, or at least a reduction of the receiver's dynamic range, and
- generate 3rd-order intermodulation products whose frequency falls into the IF-band and leads to consequences as mentioned for IF-band interference, i.e. a reduction of P_d or increase of P_{fa}.

The front-end overload will occur if the sum of signals received from interference sources, falling into the radar receiver's RF bandwidth, is strong enough to reduce the receivers dynamic range considerably or even to saturate it, resulting in gain compression of the desired signal sufficient to degrade receiver performance. This may even occur for frequencies far away from the radar’s centre frequency and useful IF-bandwidth because the RF-bandwidth of aeronautical radars may be very large (more than 100 MHz). Receiver front-end overload is typically a result of a lack of RF selectivity in the front-end of the victim receiver.

While P_d degradation by interference power entering via the IF bandwidth can be counteracted by a combination of distance and frequency separations between external interferer and victim radar receiver, the RF-front-end overloading (including intermodulation) is, because of the radar receiver's large RF bandwidth, limited to apply distance separation as an interference countermeasure.

6 DETERMINATION OF INTERFERENCE FROM ENG/OB INTO RADAR RECEIVERS

It is important to note that since the band 2700-2900 MHz is allocated world-wide on a primary basis to the aeronautical radionavigation service, which is a safety of life service, the appropriate analysis methodology must be used and extreme care taken in determining interference potential to this service (S4.10 of the Radio Regulations).

The methodology used in this report is based on the methodology in the Recommendation ITU-R M.1461.

6.1 Calculation of interference level

For the determination of the maximum permissible interference level both above mentioned interference mechanism (receiver front-end overload saturation and desensitisation resulting in detection probability degradation) must be considered in combination, and the worse of the two results defined as acceptable limit.

6.1.1 RF-band interference

To prevent dynamic range reduction as well as energy transfer from the RF into the IF bandwidth within the radar receivers, it is necessary to limit interference power cumulated over the whole RF bandwidth below the 1 dB compression point of the radar's receiver chain. The actual necessary value of this protection criterion may vary for different radar systems and must therefore be determined for each system independently.

The input threshold at which radar front-end overload occurs is a function of the 1 dB gain compression level and the gain of the radar front-end or LNA. Specifically:

$$T = C - G \qquad (1)$$

where:

T - input threshold at which radar front-end overload occurs (dBm),
C - output 1 dB gain compression (saturation) level of the radar front-end or LNA (dBm),
G - gain of the radar front-end or LNA at the interferer fundamental frequency (dB).

Furthermore, it has been proposed that an additional margin to be determined individually for each radar and interference type be considered, which will lead to an alternative equation (1): $T = C - G - K$, where K(dB) is the eventual additional saturation margin. The range of value for the margin below the 1 dB compression point may vary (in this study, the values of 0 and 15 dB are considered).

A potential for interference from receiver front-end overload will exist whenever:

$$I_T = T - FDR_{RF} \qquad (2)$$

where:

I_T - interferer signal level at the radar antenna output or receiver input that causes receiver front-end overload (dBm),
T - input threshold at which radar front-end overload occurs (dBm),
FDR_{RF} - frequency dependent rejection of the interferer fundamental from any RF selectivity that may be ahead of the radar RF amplifier (LNA) or that may be inherent in the RF amplifier (LNA) itself.

Equation (3) can be used to determine whether radar front-end overload is likely when interferers operate within particular distances of radar and are separated in frequency by certain amounts:

$$I = P_T + G_T + G_R - L_T - L_R - L_P \qquad (3)$$

where:

I - peak power of the interferer, at its fundamental frequency, at the radar antenna output or receiver input (dBm)
P_T - peak power of the interferer transmitter (dBm),
G_R - main beam antenna gain of the radar (dBi),
G_T - interferer transmitter antenna gain in the direction of the radar station under analysis (dBi),
L_T - insertion loss in the interferer transmitter (dB),
L_R - insertion loss in the radar receiver (dB),
L_P - propagation path loss between transmitting and receiving antennas (dB).

In determining the propagation path loss, appropriate propagation models and possible indirect coupling should be used taking into consideration antenna heights and terrain when appropriate. If the calculated peak power of the radar pulses, at the fundamental frequency, I, exceed the threshold at which receiver front-end overload occurs, I_T, necessary steps to ensure compatibility need to be taken.

6.1.2 IF-band interference

In order to determine the required geographical separation distance versus carrier separation, which will not degrade the radar detection performance for a range of I/N ratios, the calculations are based on the following assumptions.

The maximum permissible interfering signal level, I_T, is determined by:

$$I_T \text{ (dBm)} = I/N\text{(dB)} + N\text{(dBm)} \qquad (4)$$

where:

I/N - the interference-to-noise ratio at the detector input (IF output) necessary to maintain acceptable performance criteria, in dB (long term criterion provided in ITU-R M.1464),

N - the receiver inherent noise level, in dBm, $N = N\text{(dBm/MHz)} + 10\log B_{IF}\text{(MHz)}$.

where:

B_{IF} - the radar receiver IF bandwidth, in MHz; N(dBm/MHz) is given in the radar's characteristics tables in Annex 1.

The following equation can be used to determine whether systems in other services can operate within particular distances of radars and are separated in frequency by certain amounts:

$$I = P_T + G_T + G_R - L_T - L_R - L_P - FDR_{IF} \qquad (5)$$

where:

I - the peak power of the undesired signal at the radar receiver input, dBm,

P_T - the peak power of the undesired transmitter under analysis, dBm,

G_T - the antenna gain of the undesired system in the direction of the radar under analysis, dBi,

G_R - the antenna gain of the radar station in the direction of the system under analysis, dBi,

L_T - the insertion loss in the transmitter, dB,

L_R - the insertion loss in the radar receiver, dB,

L_P the propagation path loss between transmitting and receiving antennas, dB,

FDR_{IF} - the frequency-dependent rejection produced by the receiver IF selectivity curve on an unwanted transmitter emission spectra, in dB.

The FDR value can be determined from Recommendation ITU-R SM.337-4. Calculation of the FDR, requires the radar receiver intermediate frequency (IF) selectivity response and the emission spectrum characteristics of the other system transmitter.

In determining the propagation path loss, appropriate propagation models and possible indirect coupling should be used taking into consideration antenna heights and terrain when appropriate. If the calculated peak power of the undesired station at the radar receiver input (I) exceeds the threshold at which receiver performance degrades, I_T, necessary steps to ensure compatibility need to be taken.

In case of more than one interference source in the area covered by the radar antenna's main lobe, aggregation of the signal power of all simultaneously contributing sources has to be performed (see ITU-R M.1464).

Since ARNS is a safety-of-life service and therefore the maximum permissible interference level must never be exceeded (no harmful interference), a conservative approach including safety factors is necessary for determining the appropriate propagation model. This is covered by applying the ITU-R Rec. P.452 and implies to use a line-of-sight (LOS) propagation model.

To ensure the criterion above, the following assumptions have been made in the implementation of the equation (5) above:

- No additional losses have been considered within the study for:
  - additional propagation losses,
  - polarisation loss,
  - system losses,
  - terrain shielding effect,
  - building shielding effect,
  - potential building penetration;
- Furthermore main beam to main beam coupling has been used;
- Short time propagation enhancements (due to ducting or focusing effects, see Rec. ITU-R P.452) also included.

The correction factor in dB for multipath and focusing effects is as follows:

$$E_S(p) = 2.6\,(1 - e^{-d/10})\,\log\,(\,p\,/\,50) \qquad (6)$$

where p is the time percentage(s) for which the calculated basic transmission loss is not exceeded and d is the distance in km (longer than 5 km).

Applicable percentages of time for calculating the size of such enhancements will still have to be agreed on.

When combining the effects of both interference mechanisms (receiver front-end overload and desensitisation) the larger one of the two necessary distance separations must be taken as the protective measure.

Usually, the Intermediate Frequency selectivity characteristic is the most important factor in determining the receiver ability to discriminate against interference. Thus, the necessary frequency separation between radars and an interfering system strongly depends on this characteristic of the victim receiver.

The Intermediate frequency filters have been modelled in this study with Butterworth filters which give bandwidth values at –3 dB and –60 dB levels very close to the provided values. Furthermore, due to non-ideal filter characteristics, which do not allow for attenuation in excess of 70 dB, a flat shape is assumed after this maximal attenuation. The shapes of the modelled radar receiver filters are shown in Annex 2.

Recommendation ITU-R M.1461 recommends that an I/N ratio of –6 dB should be used if no specific ratio is provided for the radar being analysed. ITU-R M.1464 (which deals with the characteristics and protection criteria for radionavigation and meteorological radars operating in the frequency band 2700-2900 MHz) also gives this value (although there have been activities initiated to revise ITU-R M.1464 with a proposed new value of –10 dB).

Following theoretical considerations about the impact of interference (taken as additional white noise) on the SNR and on a simple radar detector (envelope detector), it is shown that for the typical performance of a single channel of a diversity-channel PSR (Primary Surveillance Radar) small variations in SNR can cause a large impact on the P_d (see Figures 6.1 and 6.2 below). Furthermore an I/N ratio of –6 dB causes a reduction of nearly 1 dB of SNR and an I/N of –10 dB still causes a loss of 0.4 dB (see Figure 6.1).

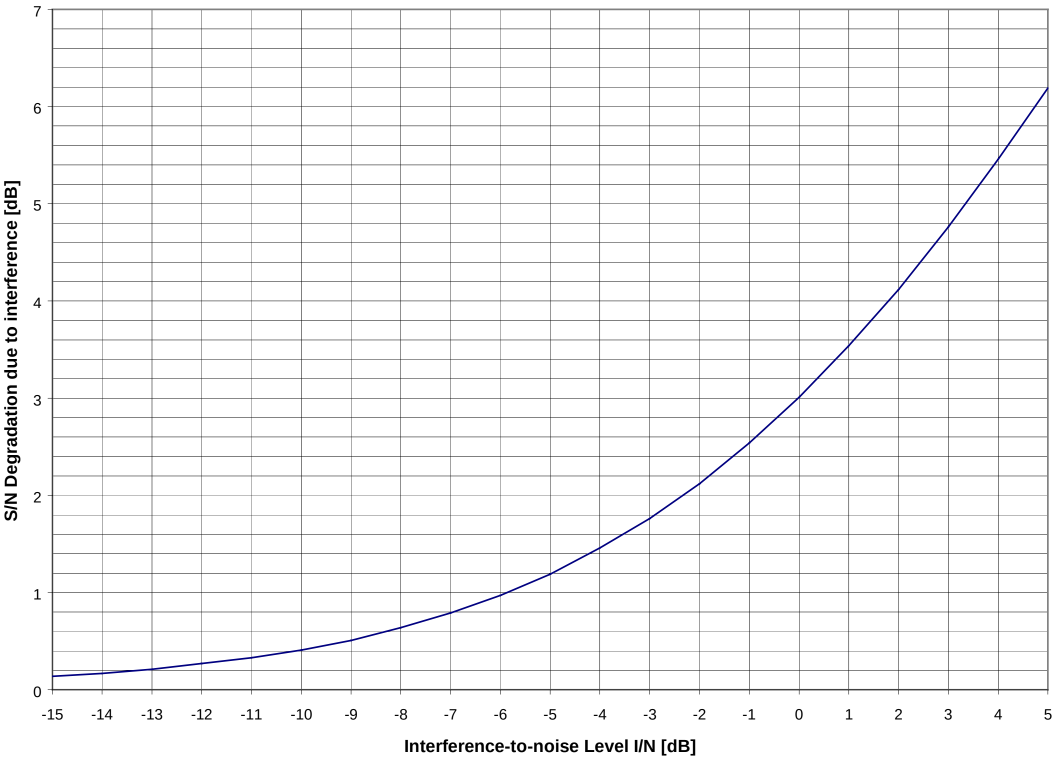

Figure 6.1: Reduction of S/N due to (noise-like) interference level given on abscissa (relative to system inherent noise N)

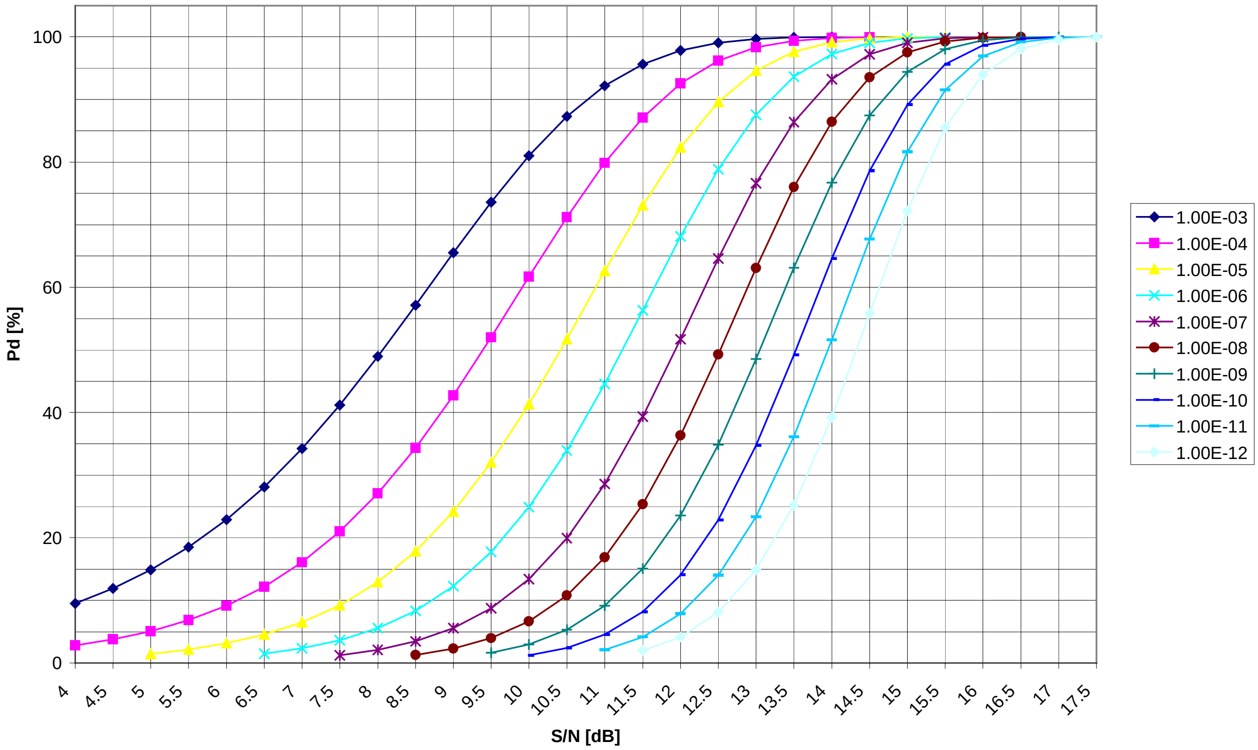

Figure 6.2: Detection probability P_d as a function of S/N, for false alarm rates between 10^{-3} (left-most curve) and 10^{-12} (right-most curve), for white noise, envelope detector and constant S/N (independent of target range).

To obtain more specific protection criteria for given radar, measurements need to be carried out (following the procedures given in chapter 6.2).

6.2 Measurement procedures for assessing the impact of interference on radar performance

The impact of digital ENG/OB interference upon an aeronautical radar can be measured by injecting artificially generated interference signals into the radar receiver, while simultaneously measuring P_d degradation by means of an objective recording tool, taking opportunity air traffic as target pool and the radar's diversity channel and/or any co-sited secondary surveillance radar's target plots as a reference. Interference injection should happen at the earliest possible point of the receiver chain (in any case before the LNA) to include the influence on the whole receiver and not only on parts of it.
Possible interference signals might be:

- continuous wave (single tone sine-wave at different frequencies),
- broadband Gaussian white noise,
- digitally modulated signals (especially digital ENG/OB signal employing COFDM).

The first step of the measurement procedure is the determination of the receiver’s noise level (noise power spectral density). This is best done in the IF-part of the receiver but behind the IF-filter because this is the point where I/N has to be determined.

The second step is to determine the power level of the co-frequency interference source for which I/N = 0 dB. This produces an increase of the noise power density within the receiver’s bandwidth of 3 dB (if the spectrum of the interference signal is noise-like).

The radar’s performance in the presence of interference (for different interference power levels and frequency separations), and especially the threshold at which interference starts to cause noticeable performance degradation, must be determined using appropriate tools which are able to measure the quality parameters (mainly P_d but also P_{fa} and azimuth positioning accuracy). Target test signals with known amplitudes (recorded real-world echo sequences) or real-world opportunity traffic can be used. Especially for the latter, long observation times have to be applied in order to arrive at stable estimates for P_d and P_{fa}, which are fluctuating due to varying target scenarii and parameter configurations.

This kind of measurement takes into account the operation of the radar's video processor and target prediction capabilities.

7 RESULTS OF THE SHARING STUDIES

The detailed studies below include measurements as well as theoretical calculations.

Some measurements have been performed (section 7.1) on two different radars mainly to assess the impact of digital ENG/OB signals (simulated in accordance with the DVB-T standard EN 300 744) on the performance of air traffic control radars.

Based on the ITU-R Recommendations M.1461 and M.1464 and on the results of the measurements, theoretical calculations have been conducted following the assumptions described in section 7.2.

Furthermore, these theoretical calculations have been extended to cover other new potential application (digital aeronautical telemetry) under the specific assumptions described in section 7.2.2.

7.1 Measurements

Measurements were performed on a modern system (PSR Salzburg/Haunsberg, Thales Star 2000, solid-state, pulse-compression) under well-defined conditions. Similar measurements were carried out at the PSR Graz/Thalerhof , a magnetron powered radar with short pulses (1 µs) manufactured by Thomson-CSF (Type TA 10-M).

The following information is a presentation of the measurements performed on the Salzburg Star 2000 radar.

Strategy and Conditions

Interference signals were injected into the receiver in front of the LNA (see Figure 7.1) and the influence of this interference on the detection of opportunity traffic targets was determined. For the evaluation the plot messages of the radar video processor were recorded and then evaluated by a standard Eurocontrol software tool (SASS-C).

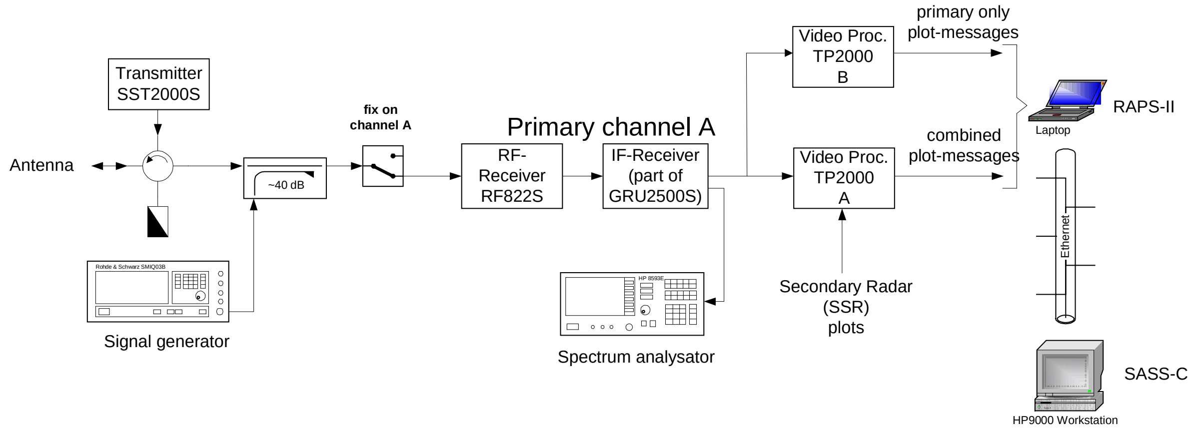

Figure 7.1: Block diagram of the measurements (Salzburg)

The formula, which is used by SASS-C to calculate the probability of detection of the primary radar, is given by the following equation:

$$P_{d\ prim} = \frac{number\ of\ \mathbf{acknowledged}\ primary\ plots}{number\ of\ \mathbf{expected}\ primary\ plots}$$

where a primary plot may be primary only or a combined plot (primary and secondary echo).

At least 50000 plots inside the primary coverage volume (<60 nmi range) were recorded for each measurement. Depending on the amount of traffic this corresponds to a duration between 1 h 20 min and 2 h.

For the actual calculation of P_d only parts of the volume were used since, due to changes in the characteristics and amount of traffic (both spatial and temporal), a restriction was necessary to ensure stable results.

Results of P_d analysis

To minimise the variations due to the changes in opportunity traffic – both in numbers and characteristics (e.g. type of aircraft) – the calculation of P_d was based only on a part of the whole coverage volume as indicated above. The chosen volume is a ring between 40 and 60 nmi and between flight level 250 and 500 (25000 – 50000 ft). In this volume the characteristics of air traffic were more constant than in any other investigated volume giving therefore the best results for the P_d evaluation. At these height levels the traffic is mainly civil aviation which means rather large aircraft and uniform flight paths. This does mean however, that the effect of interference on Pd was not calculated for the radar returns from smaller aircraft that will be flying below flight level 250 (25000 ft). As these radar returns would be of lower powers than those from larger commercial aircraft it is likely that the radar system's ability to detect these smaller targets would be more significantly affected by the interfering signal than for the large aircraft returns.

The reference P_d (measured without interference) is based on 7 single measurements carried out at different times of the day and therefore different traffic scenarios. The average P_d value of these measurements is 93.0 % with one sigma standard deviation of 0.5 %.

The aggregate P_d for the whole coverage volume of the radar was 85.8 % with a standard deviation of 1.4 %. The reason for P_d being lower than 90 %, the threshold being demanded by Eurocontrol, is most likely the lack of frequency diversity during the measurements.

Results for DVB-T signal (EN 300 744 standard):

The following parameters have been assumed: 8 MHz channel width, 2k COFDM, 16QAM.

I/N (dB)	Pd, %
0	85,0
-4	88,9
-6	90,7
-8	91,2
-10	92,2
-12	92,6
-14	92,5
-16	93,2
-20	93,7

Figure 7.2 shows these results as change of P_d (difference to the reference value of 93.0 %) together with a 3rd - order trend polynom.

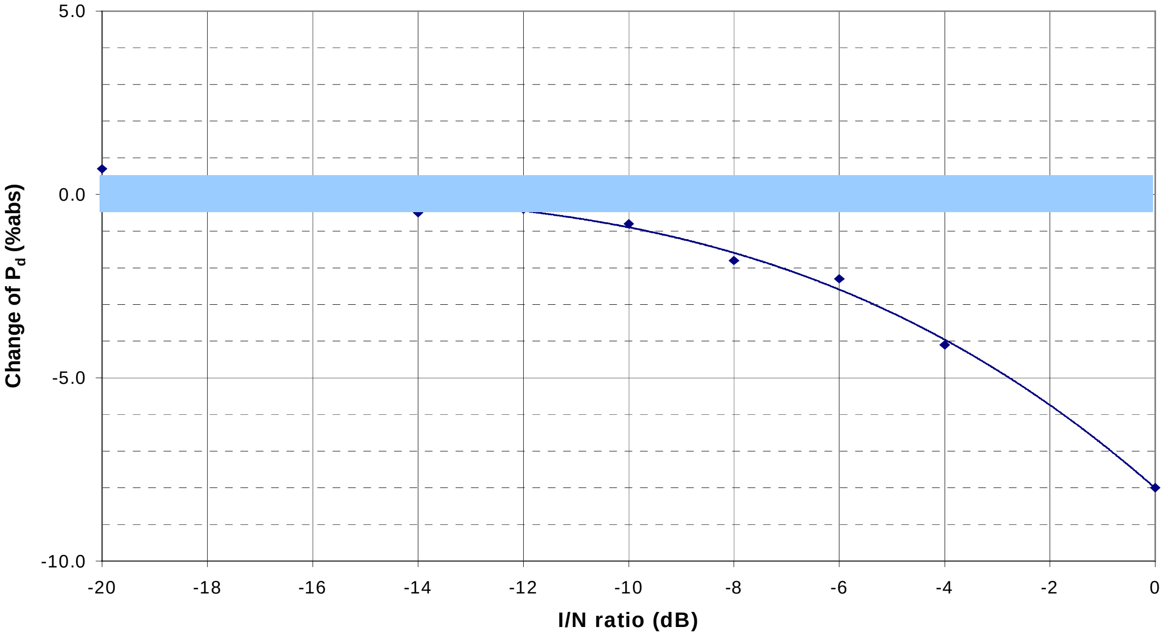

Figure 7.2: Change of P_d in case of DVB-T signal interference (relative to undisturbed case with P_d = 93 %)

Besides the DVB-T signal, measurements were also done with a Gaussian noise-like signal. Figure 7.3 shows these results and compares them to DVB-T interference. It can be seen from this diagram that a COFDM (DVB-T) signal and band-limited white noise have a similar effect on radar detection performance.

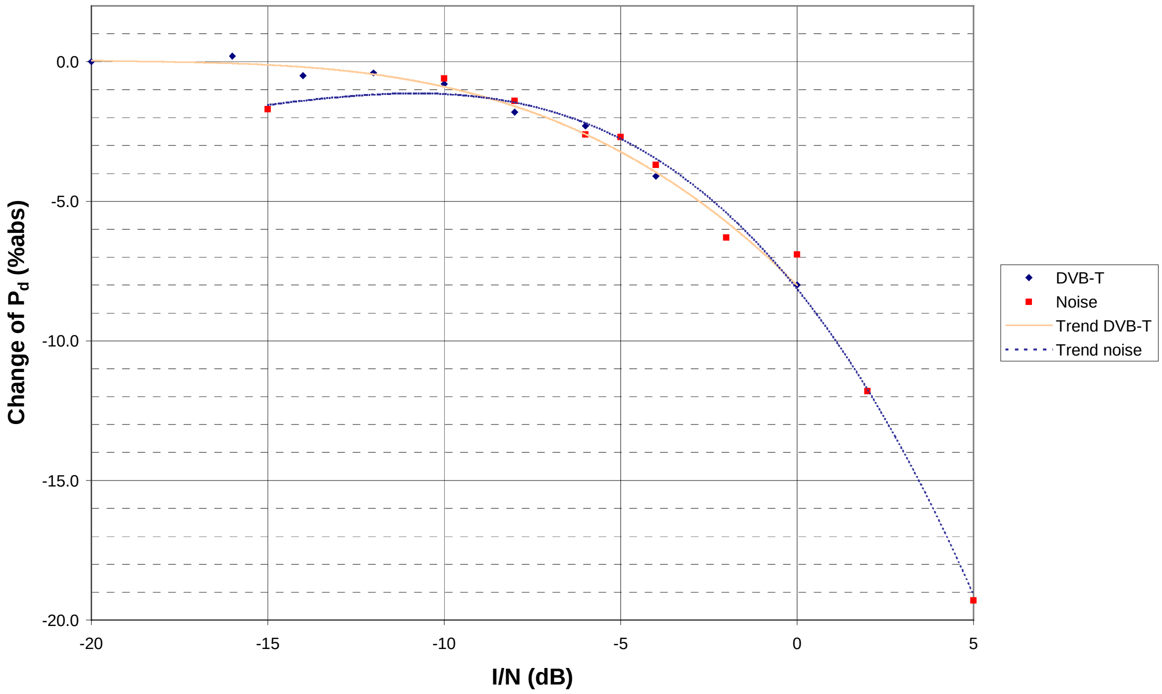

Figure 7.3: Comparison of P_d for different interference sources (range 40-60 nmi and FL 250-500)

Additional findings related to radar performance

An analysis of the accuracy of plots by determining the mean position error has shown that the accuracy decreases in a similar manner to the P_d.

The number of false plots per scan appears to be independent of the interference level (for DVB-T and noise-like signals) and its mean value is between 1 and 2 false plots per scan which corresponds quite well to a P_{fa} of 10^{-6}. Therefore it is very likely that the CFAR process is working properly under the influence of noise-like interference (at least at interference levels investigated during these measurements).

Results of measurements performed on the ASR-Graz

Measurements were done with Gaussian white noise as the interference signal. The resulting detection probability was determined by comparing the detected targets of the primary and the co-sited secondary radar. Table 7.1 shows the results of the measurements (loss of P_d, in percentage points) for this interference signal and different I/N-ratios. The reference P_d (measured in a single radar channel without interference) was assessed to be 70 % with a variation of 3 %. By using frequency diversity, the corresponding reference P_d = 90 %.

Due to the limited opportunity traffic, there is a margin of uncertainty in these results.

Table 7.1: Loss of P_d in case of interference I of level given relative to noise N

	Pd reduction (%) relative to undisturbed signal
I/N (dB)	white noise
-10	-2
-5	-6
0	-7

7.2 Separation distances

7.2.1 Calculations related to interference to radars from ENG/OB applications

Using the methodology described in chapter 6.1, separation distances as a function of frequency separation can be calculated for different values of I/N.

Recommendation ITU-R M.1461 recommends that an I/N ratio of – 6 dB should be used if no specific ratio is provided for the radar being analysed. ITU-R M.1464 (which deals with the characteristics and protection criteria for radionavigation and meteorological radars operating in the frequency band 2700-2900 MHz) also gives this value (although there have been activities initiated to revise ITU-R M.1464 with a proposed new value of –10 dB).

In addition, following the measurements on two air traffic control radars described in 7.1, it has been considered that it can be beneficial to consider also an I/N ratio of –12 dB.

Therefore, the assessment of separation distances consider three different values of the I/N ratio: –6 dB, –10 dB and –12 dB.

The input parameters for these calculations are:

- the EIRP of the interferer (in case of a cluster of sources the aggregated power must be used), for ENG/OB two values are considered (0 and 17 dBW),
- the type and bandwidth of the interference signal,
- the power transfer function of the radar receiver's IF-filter,
- input threshold at which radar front-end overload occurs. Two values of the input threshold are considered, –20 dBm, (as given in Recommendation M.1464 and validated for one class of modern radars by the measurement at the Salzburg ASR which gives a value of –24 dBm) and –39 dBm, as measured on an other operational ASR (at airport Graz/Thalerhof, Austria),

Furthermore, it has been proposed that an additional back-off margin to be determined individually for each radar and interference type be considered to assess the maximum allowable interference level. No agreement was reached on this issue. The effect of the additional back-off margin on the separation distances is presented in Figure 7.4. For the calculations, two options are considered in the calculations : no additional margin and an additional margin of 15 dB. Taking into account the two different values of the input threshold, it leads to 4 different options for the analysis of the radar receiver front-end overload (Figure 7.4).

In addition, concerning the radar characteristics, the noise level is –140.8 dBW/MHz and the peak antenna gain is 34 dBi.

Short time propagation enhancements (due to ducting or focussing effects, see Rec. ITU-R P.452) were also included, the correction factor for multi-path and focussing effects being calculated according to the procedure described in 6.1.2.

There was no agreement on the value of the time percentage p to use in the equation 6. For the purpose of the studies, it was set to 0.1 % which leads to an enhancement of 4.4 dB at 10 km and 7 dB at 100 km.

Required geographical separation distances (km) between interferer (ENB OB) and victim (radars with low/high selectivity) vs. separation in centre frequency (MHz) are shown in the Figures 7.5(a,b) and 7.6(a,b) for various radar protection criteria (I/N = -6 dB, -10 dB and –12 dB).

Assuming LOS-propagation and co-channel operation ($\Delta f=0$ in Figures 7.5(a,b) and 7.6(a,b)), separation distances in the order of 400 km as given in the figures result from altitudes in the order of 10 km.

However, for digital cordless camera applications considered in this report (see Annex 3), use will generally be at altitudes less than 10 km (which is relevant for aeronautical telemetry) and, consequently, it is expected that separation distances will be lower. Nevertheless, due to propagation effects, co-channel separation distances may exceed the radio horizon.

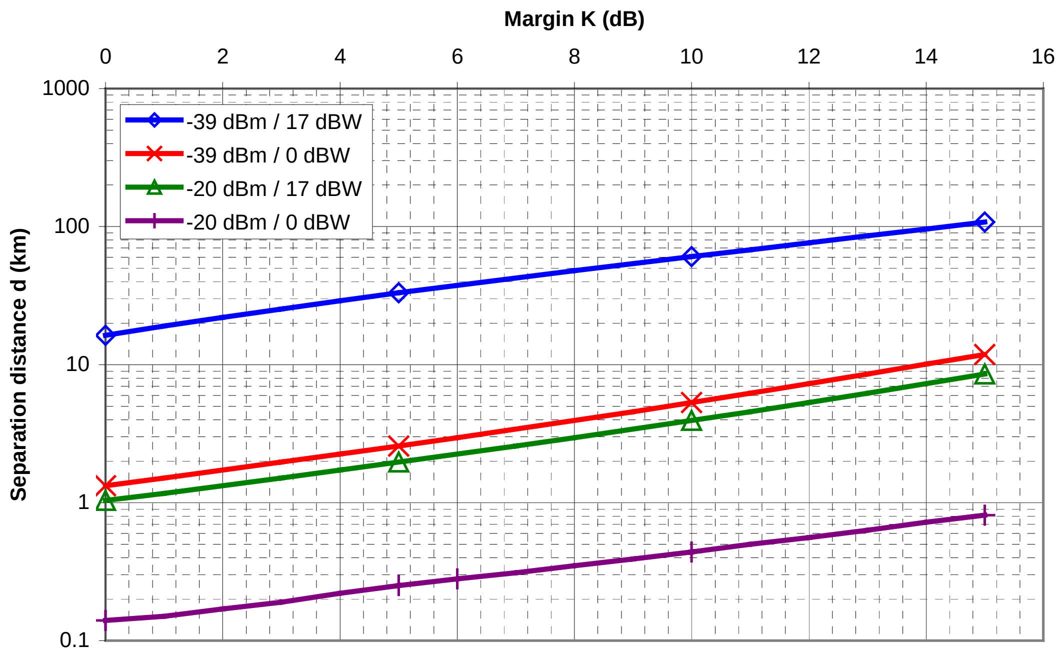

Figure 7.4: Separation distances necessary to prevent radar's receiver front-end saturation (parameters: saturation threshold, EIRP)

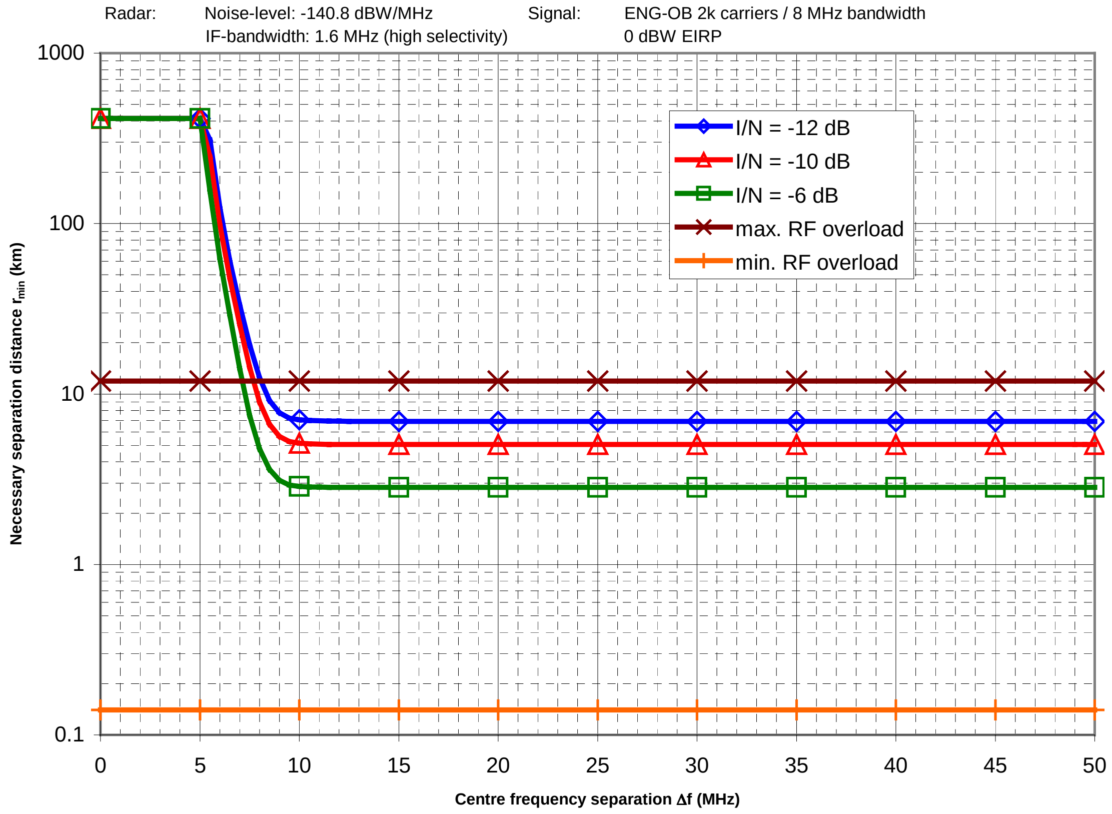

Figure 7.5(a): Separation distance to protect high selectivity radar from 0 dBW ENG/OB OFDM signal (parameter: Maximum tolerable interference-to-noise ratio at radar receiver)

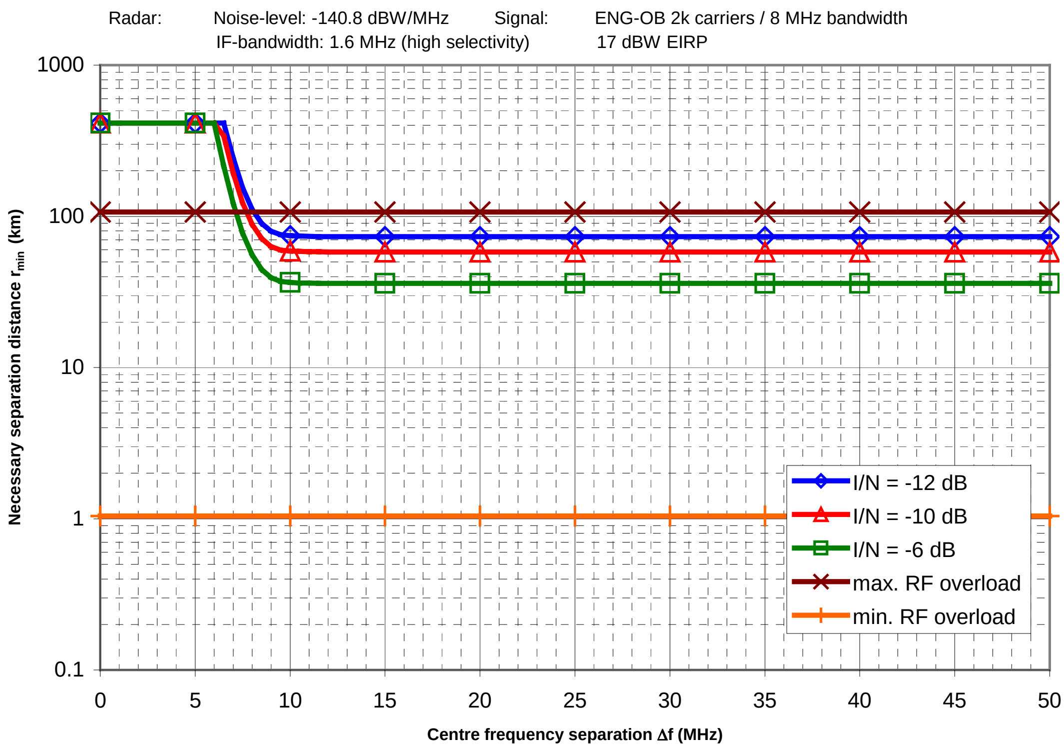

Figure 7.5(b): Separation distance to protect high selectivity radar from 17 dBW ENG/OB OFDM signal (parameter: Maximum tolerable interference-to-noise ratio at radar receiver)

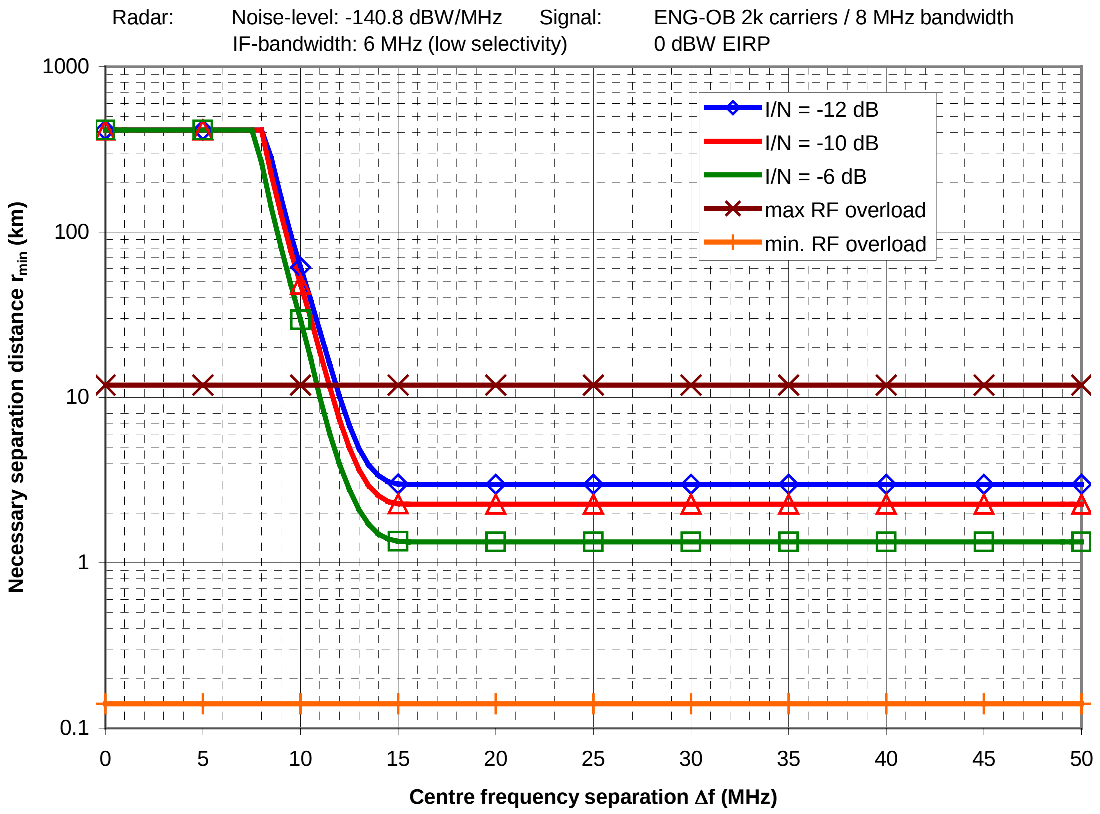

Figure 7.6(a): Separation distance to protect low selectivity radar from 0 dBW ENG/OB OFDM signal (parameter: Maximum tolerable interference-to-noise ratio at radar receiver)

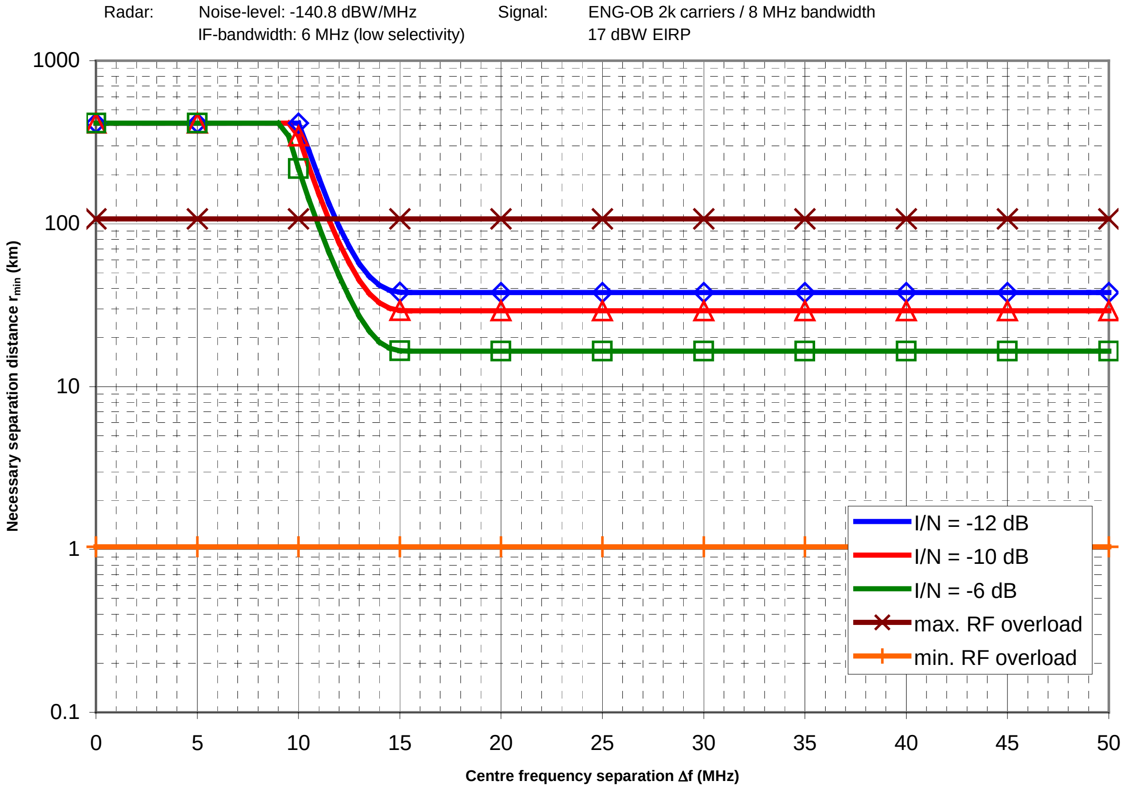

Figure 7.6(b): Separation distance to protect low selectivity radar from 17 dBW ENG/OB OFDM signal (parameter: Maximum tolerable interference-to-noise ratio at radar receiver)

7.2.2 Example of calculation of separation distances for interference to radars from digital aeronautical telemetry

Planned characteristics for digital aeronautical telemetry

Like for digital ENG/OB – as described above – the use of COFDM is also envisaged for the modulation of the aeronautical telemetry signal (the number of carriers is not known yet but may be in the same order of magnitude as for digital ENG/OB, namely 2k). A transmitter output power of 15 W (11.8 dBW) will be used and together with an omni-directional antenna with gain 0 dBi and EIRP of 11.8 dBW. A smaller than for digital ENG/OB bandwidth of 5 MHz will be necessary.

It should be noted that no ETSI standard is currently available, i.e. the given characteristics are assumptions only. However, variation in EIRPS, propagation, aggregation etc is covered by the correction in distance provided in section 7.3.

Radar receiver protection criteria

Unlike for the above described case of digital ENG/OB signal, no actual interference measurements were carried out at an aeronautical radionavigation radar to determine the necessary I/N ratio for this type of signal.

But under the assumption that the above described characteristics will be used, it can be very much assumed that the digital aeronautical telemetry signal will behave like band-limited Gaussian noise very similar to the ENG/OB signal. Under such conditions the impact of different I/N ratios on the radar performance (mainly P_d) should be similar to the results gained by measurements with ENG/OB or noise-like signals as shown in chapter 7.1 (at least for radars with a high-selectivity IF-filter where the filter bandwidth is smaller than the interference signal bandwidth, for low-selectivity radars there probably will be a significant difference).

Regarding the possibility of saturation of the radar's RF front-end, the considerations used for ENG/OB (see section 6.1.1) apply also for this case since only the power of the interference signal and not its structure is responsible for LNA saturation.

Required separation distances
For the calculation of the necessary separation distances in the case of digital aeronautical telemetry, the same protection criteria as in chapter 7.2 for digital ENG/OB can partly be applied. A theoretical extrapolation covering the interference source digital Aeronautical Telemetry can be performed. This extrapolation is valid only for the same type of DVB-T signal as used for the ENG/OB service, except of the bandwidth (5MHz instead of 8MHz) and an EIRP of 11.8dBW.

In the case of aeronautical telemetry, it is even more important to use worst-case conditions (like the consideration of the line-of-sight propagation including multi-path effects and other propagation enhancements) since aeronautical telemetry has an airborne transmitter of unknown height and changing position. Therefore line-of-sight may apply more often for this service and additionally the lobbing effects of the radar antenna are more likely to occur (i.e. enhancements of the antenna gain due the mirror effect of the earth surface which vary very much for different elevation angles).

Concerning radar characteristics, the same assumptions as in the calculations dealing with digital ENG/OB (see section 7.2) have been taken.

Therefore the required geographical separation distances (km) between interferer (Aeronautical Telemetry with the assumed EIRP of 11.8 dBW, assuming a maximum altitude of 10 km) and victim (radars with low/high selectivity) vs. separation in centre frequency (MHz) are shown in the Figures 7.7 - 7.8 for various radar protection criteria (I/N of -6 dB, –10 dB and –12 dB).

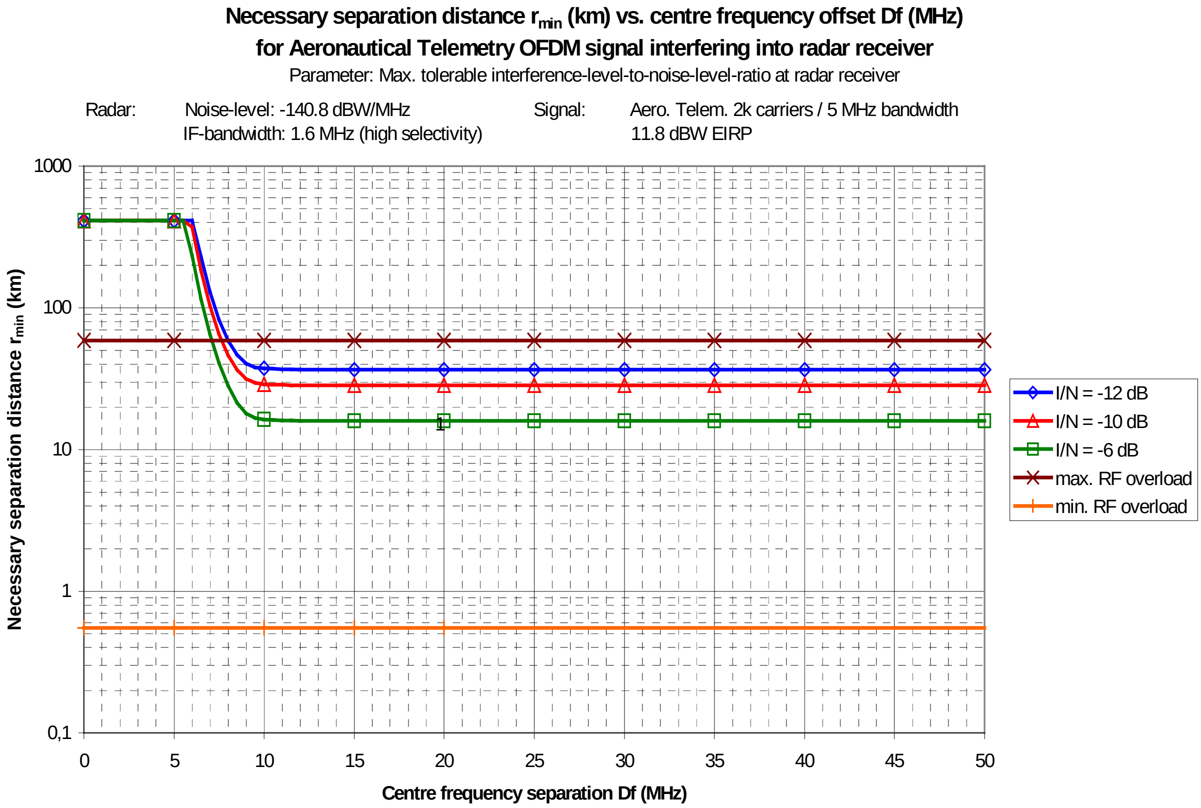

Figure 7.7: Separation distance to protect high selectivity radar from 11.8 dBW Aeronautical Telemetry (parameter: Maximum tolerable interference-to-noise ratio at radar receiver)

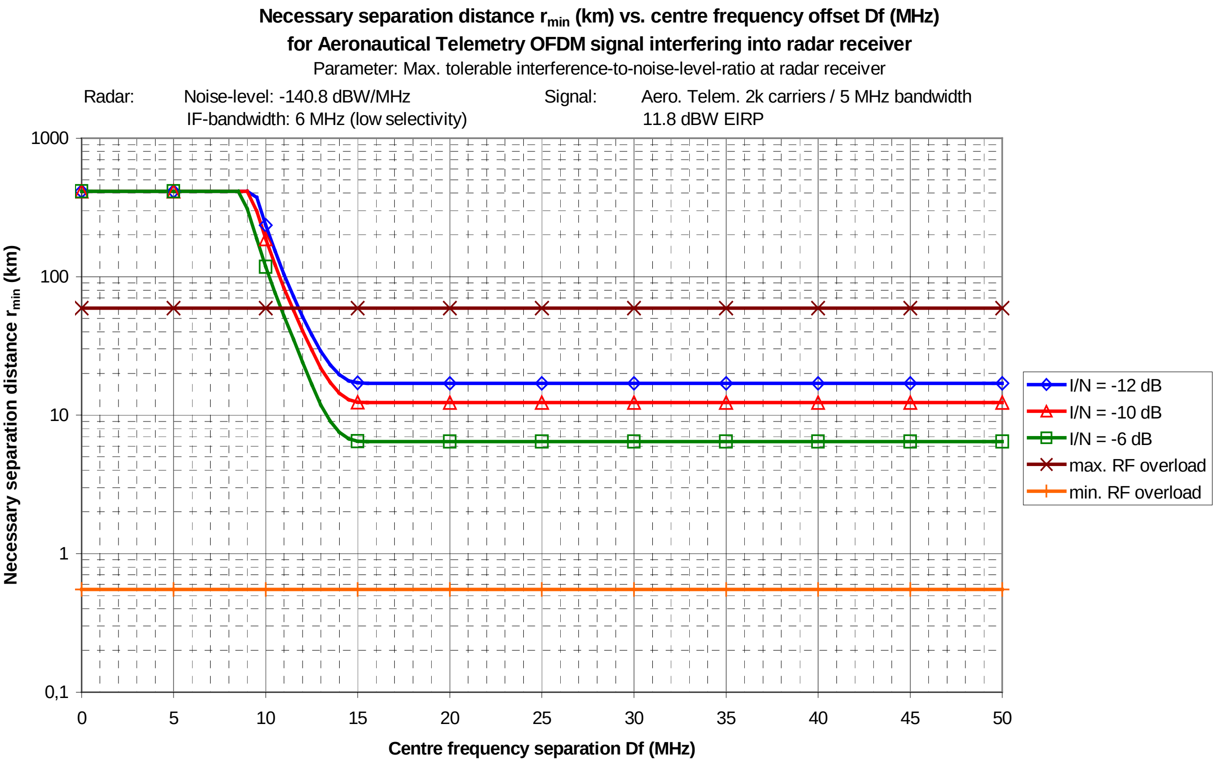

Figure 7.8: Separation distance to protect low selectivity radar from 11.8 dBW Aeronautical Telemetry (parameter: Maximum tolerable interference-to-noise ratio at radar receiver)

7.3 Correction of calculated geographical separation distances due to variation in EIRP, propagation, aggregation effects

The curves in Figure 7.9 show the impact of additional loss of interfering signal.

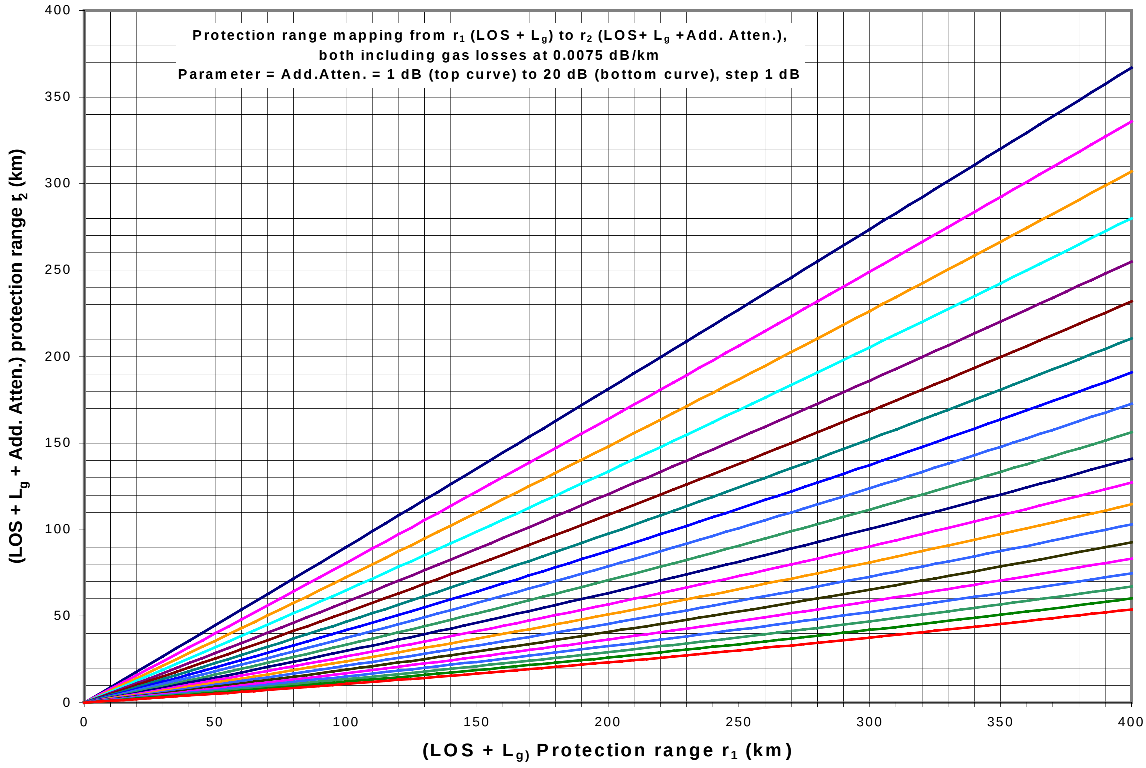

Figure 7.9: Correction of separation distance in case of increase or reduction of the interferer's power level at the radar receiver (top curve: -1 dB, bottom curve: -20 dB)

The curves in Fig. 7.9 can be used to modify the separation distances in case of additional attenuation due to propagation enhancements, variation in EIRP and/or aggregation. (e.g. if an additional attenuation of 2 dB has to be taken into account and the original separation distance is 100 km (from one of Figures 7.5 to 7.8) a vertical line has to be drawn from the value 100 at the abscissa of Figure 7.9 to the 2 dB curve (the 2nd one from the left) and then straight to the ordinate on the left where a value of about 80 km can be obtained. In the case of an aggregation (for example, a cluster of 4 sources increasing the power level by a maximum of 6 dB) you use Figure 7.9 the other way round: 100 km at the ordinate → 6 dB curve → about 185 km separation distance on the abscissa).

8 CONCLUSIONS

This report was initiated by the proposed use of two new planned mobile telecommunication applications, Digital ENG/OB (Electronic News Gathering/Outside Broadcast; ground-based) and Digital Aeronautical Telemetry (down-link) transmissions, to access and use frequencies in the band 2700 to 2900 MHz (S-band), allocated on a primary basis to aeronautical radio navigation services (radars) and meteorological radio location.

The main purpose of this report is to study the possibility of the introduction of digital ENG/OB in the band 2700-2900 MHz. This is done by estimating the potential interference from ENG/OB to radars. Further studies may be needed to assess the other direction of interference (i.e. from radars to ENG/OB).

In addition, the calculations are extended to comparable potential new radio-applications (digital aeronautical telemetry).

Further studies should be conducted to assess the possibility of coexistence between radar systems and digital ENG/OB in other frequency bands, such as 2900-3400 MHz.
Considering that the existing aeronautical radionavigation systems (ARNS) have to provide safety-of-life services for air traffic guidance and control, every possible precaution has been taken in the determination of the required sharing conditions and restrictions related to potential band sharing between existing and new applications.

This report, to the extent possible was based on relevant ITU-R Recommendations for propagation, methodology and radar characteristics such as the most recent versions of ITU-R Recs. P-452, M.1461 and M.1464. However, in accordance to common practice, considering that ARNS is a safety-of-life service (RR S1.59 and S1.169), the following worst case assumptions have been applied to the calculations of interference from the ENG/OB as well as from the Aeronautical Telemetry:

- Line-of-sight propagation conditions (even beyond horizon), i.e. no additional attenuation due to obstacles included;
- Short time propagation enhancement due to ducting or focusing effects even at short distances (There was no agreement on the value of the time percentage p to use in the equation 6. For the purpose of the studies, it was set to 0.1 % which leads to an enhancement of 4.4 dB at 10 km and 7 dB at 100 km.);
- Main beam-to-main beam coupling between victim and interfering station;
- Range of protection criteria (I/N) requirements of radar receivers including more stringent criteria than current ITU-R recommended values. On-going work within ITU-R WP 8B to revise the current recommended protection criteria I/N=-6 dB, specifically for radars operated as systems in safety-of-life services. Taking into account that the I/N-ratio is a characteristic of a given radar under a certain set of operational conditions, proposed amendments to ITU-R Rec. M.1464 indicates more stringent radar protection than provided by the existing recommended protection criteria.

The calculations presented in this report are based on a single interferer, i.e. without the effect of aggregation due to a number of interferers. However, in the consideration of the probability of more than one interferer, the worst-case assumptions (main-beam-coupling) need to be taken into account.

It‘s worth noting that the report considers only technical aspects. Frequency management aspects such as judgements dealing with the feasibility of sharing are not included.

Thus, the report is focussed on the impact of 8 MHz COFDM signals (ENG/OB-like)[*] on Primary Surveillance Radars (PSR).

The impact is presented in terms of calculated protection distances versus minimum required separation in frequency for a range of protection criteria (Interference-to-Noise ratio I/N) as well as detailed measurements in terms of potential saturation effects on the receiver front-end amplifier.

Further, the impact of various I/N-values on the probability of detection is considered in the report in terms of on-site measurements based on injection by a 8 MHz 2k COFDM –signal as well as white noise.

For Aeronautical Telemetry, using radio horizon calculations and ignoring over the horizon effects, co-channel separations distances of 400km are required (corresponding to an aeronautical telemetry transmission altitude of around 10 km). Due to the large separation distances, cross-border co-ordination would be required.

For digital cordless camera applications considered in this report (see Annex 3), use will generally be at altitudes less than the 10km quoted for aeronautical telemetry and, consequently, it is expected that co-channel separation distances will be lower. However, an appropriate level of co-ordination (national or international) will still be necessary. It is to be noted that, due to propagation effects, co-channel separation distances may exceed the radio horizon.

In order to investigate the impact of various radars on required geographical separation distance, the calculations are carried out for two different categories of IF-selectivity (low/high) radar receivers.

Even though no military radar systems, or radiolocation, are considered in either of the studies, it‘s worth noting that the considered radar characteristics are implemented in some military systems as well.

The presented calculations/measurements are based on magnetron radars as well as the next generation of solid-state pulse compression radars.

By considering a single ENG/OB-like interferer represented by a 8 MHz 2k COFDM signal the following range of required geographical separation distance has been calculated:

High-selectivity radar and EIRP (ENG/OB) of 0 dBW [*]:

The required geographical separation distance between interferer and victim, at a minimum frequency separation of 10 MHz, is within the range 3-8 km dependent on required radar protection I/N= -6 to –12 dB (the more stringent protection criteria corresponds to the longer distance). Corresponding distance for EIRP 17 dBW is within the range 40-80 km.

Low-selectivity radar and EIRP (ENG/OB) of 0 dBW [*]:

The required geographical separation distance between interferer and victim, at a minimum frequency separation of 15 MHz, is within the range 1.5 - 3 km dependent on required radar protection I/N= -6 to –12 dB. Corresponding distance for EIRP 17 dBW is within the range 20-40 km.

A theoretical extrapolation has been included in the report for a single Aeronautical Telemetry-interferer assuming that the interfering signal, represented by a 5 MHz 2k COFDM –signal, has the same impact on the operational performance as the examined ENG/OB-signal (no Harmonised standard available for the Aeronautical Telemetry).

Based on this assumption, the following range of required geographical separation distances have been calculated:

High-selectivity radar and EIRP (Aeronautical Telemetry) of 11.8 dBW:

The required geographical separation distance between interferer and victim, at a minimum frequency separation of 10 MHz, is within the range 16 - 40 km dependent on required radar protection I/N= -6 to –12 dB (the more stringent protection criteria corresponds to the longer distance).

Low-selectivity radar and EIRP (Aeronautical Telemetry) of 11.8 dBW:

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[*] It should be noted that future Digital ENG/OB systems are expected to be implemented in accordance to the standard provided in EN 300 744.

[*] EIRP = 0 dBW is recommended for typical digital cordless cameras (Annex 3). EIRP = 17 dBW is included as an example value for portable links (Annex 3).

> The required geographical separation distance between interferer and victim, at a minimum frequency separation of 15 MHz, is within the range 6 - 18 km dependent on required radar protection I/N= -6 to –12 dB.
> It should be noted that for EIRPs (Aeronautical Telemetry) above the assumed power level (11.8 dBW) increased geographical separation distance at a given frequency separation will be required. Guidance is given in the report for the appropriate correction of the separation distance corresponding to a variation of 1-20 dB (Figure 7.9).

In addition to the calculations above, the separation distances, required to prevent radar receiver from front-end saturation, were calculated at the following two different over-load levels:

(1) -20 dBm (given in an example in ITU-R Rec M.1464 and validated by the measurements on some modern radars)
(2) -39 dBm (measured on the radar at airport Graz/Thalerhof, Austria).

Furthermore, an additional margin has been proposed to be determined individually for each radar and interference type considered to assess the maximum allowable interference level. No agreement was reached on this issue. Consequently, in the calculations, two options are considered: no additional margin and additional margin of 15 dB.

By using the recommended EIRP=0 dBW for digital cordless cameras (ENG/OB), the calculations showed that the radar receiver was saturated at distances below 20 km at the more stringent saturation level of -39 dBm taking into account an additional margin of 15 dB. Corresponding distance at the saturation level of -20 dBm, without any additional margin, showed to be less than 1 km (around 200 m).

By using the example value of EIRP =17 dBW for portable links (ENG/OB), the calculations showed that the radar receiver was saturated at distances up to 120 km at the more stringent saturation level of -39 dBm. Corresponding distance at the saturation level of -20 dBm showed to be around 1 km.

The comprehensive measurements, based on injection by the interferer, on ARNS-radars (Magnetron/Solid state) in operation focus on the reduction in the probability of detection due to interference from a ENG/OB-like signal (8 MHz 2k COFDM) as well as a noise-like signal. With a reference detection probability of 93 % (no interference) the measurements showed a range of 90.7 – 92.6 % probability of detection (Solid state radar) at the protection level (I/N) of -6 to –12 dB. No significant difference, with regard to impact on the radar performance, was observed between noise and ENG/OB signal as interferer.

Corresponding detection performance of the Magnetron radar (white Gaussian noise as interferer) was slightly worse, possibly due to limited traffic.

Finally, it should be noted that the study addresses radars with typical characteristics. Thus, national exemptions from the determined sharing conditions can not be excluded although the radar types used in the tests are widely deployed in Europe and elsewhere.

ANNEX 1

Characteristics of radars in the 2700-2900 MHz band for aeronautical radionavigation and meteorological applications

	Aeronautical Radionavigation radars Using magnetrons	**Aeronautical Radionavigation radars (TWT)**	**Aeronautical Radionavigation radars (Solid state)**	**Meteorological radars**
Frequency	2750 and 2850	2700 – 2900 MHz	2770 and 2840 MHz	2800 MHz
Modulation	P0N	PON, Q3N	fixed frequency for short pulse "S" modulation for long pulse (ΔF=1 MHz)	P0N
Tx Power into Antenna	500 kW	70 kW	18 kW	650 kW
Pulse width	1 μsec	0.4- 20 or 0.5 - 27 μsec depending on the range	1 μsec (short pulse) – 75 μsec (long pulse)	2 μsec or 1 μs
Pulse rise/fall time	<0.15 μsec	0.1 μsec typical	<0.1 μsec	<0.15 μsec
Pulse repetition rate	1000 pps	840 – 1100 pps	10000 pps (short pulse) 850 to 1150 pps (long pulse)	800-1860 pps
Scan rate - **horizontal** - **vertical**	90 degrees/sec N/A	60 – 90 degrees/sec N/A	90 degrees/sec N/A	1 to 30 degrees/sec volume scan is made up of a series of constant-elevation round scans, so elevation steps are done after each rotation
Peak antenna gain	33.5 dBi	33.5 dBi	34 dBi	40 dBi or 44 dBi
Beamwidth (3 dB) **-Elevation** **-Azimuth**	4.8° 1.44°		6° 1.4°	1.3° or 1 ° 1.3° or 1 °
RF receiver bandwidth - **-3 dB** - **-60 dB**	> 200 MHz	400 MHz	15 MHz 72 MHz	400 MHz
Rx IF Bandwidth - **-3 dB** - **-60 dB**	1.6 MHz 16.6 MHz	4 MHz		0.600 MHz or 1.2 MHz 10.0 MHz or 20 MHz
Receiver noise figure	2 dB	2 dB		2.5 dB
Receiver noise	-140.8 dBW/MHz			- 142 dBW/MHz

ANNEX 2
Shapes of radar receiver if filters used in the calculations

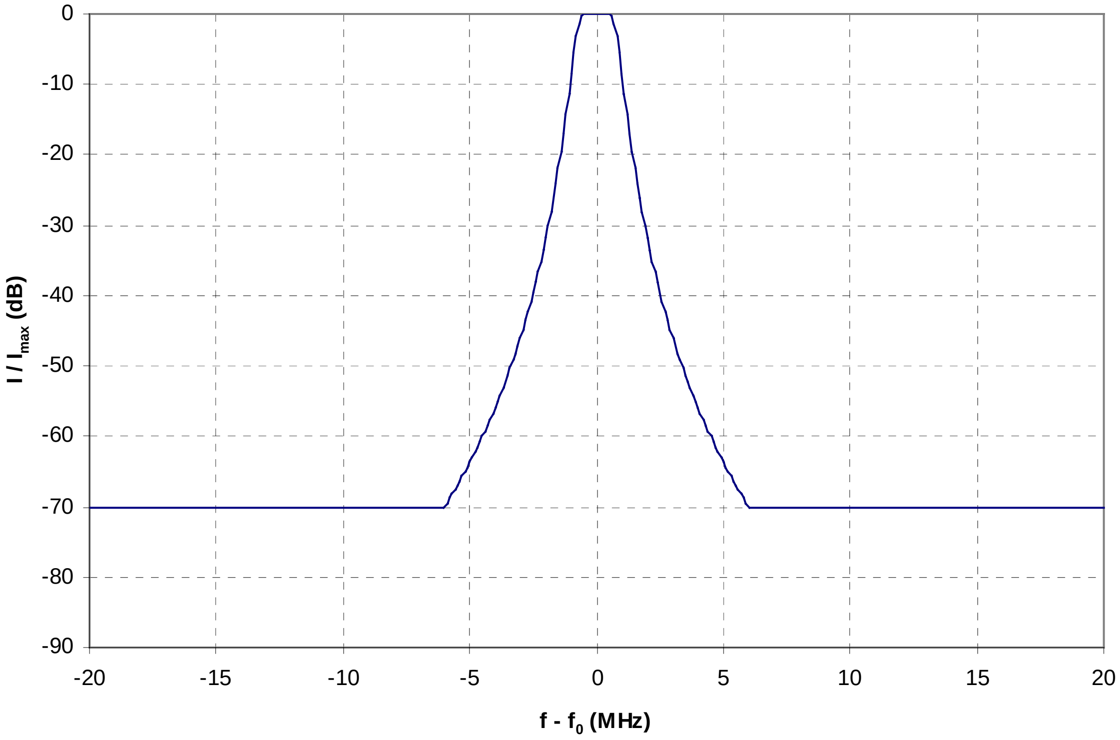

Figure A2.1: High selectivity modelled radar receiver IF filter

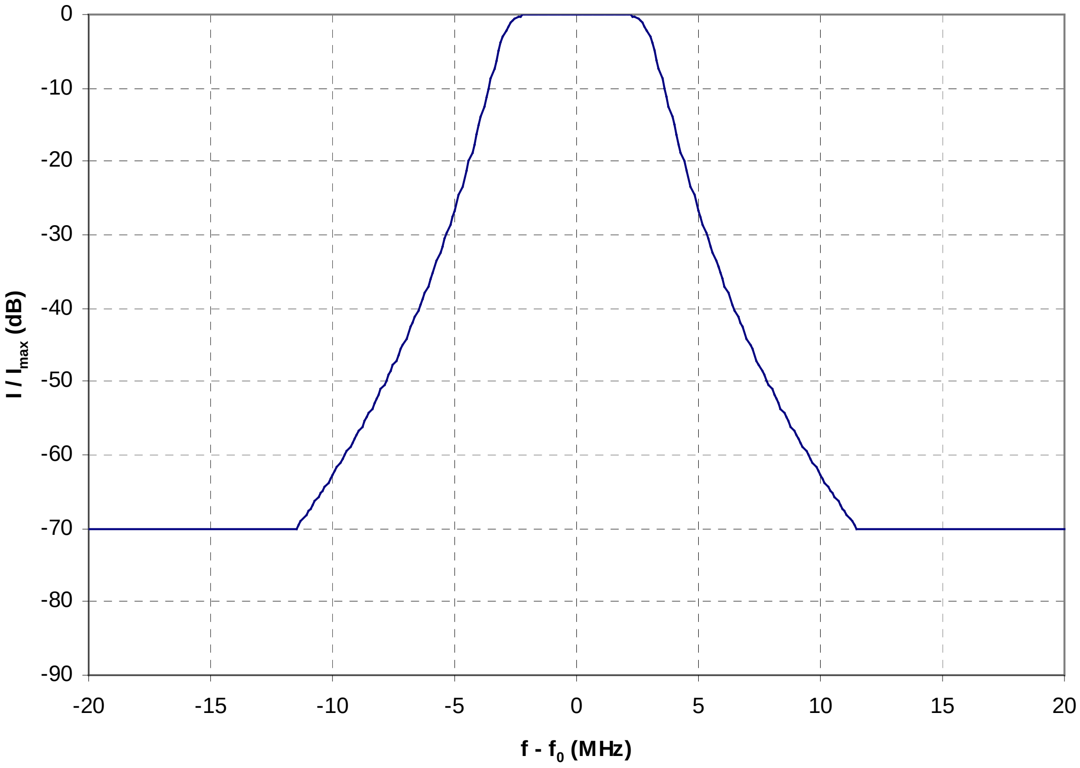

Figure A2.2: Low selectivity modelled radar receiver IF filter

ANNEX 3

Potential ENG/OB applications and assumed characteristics for digital equipment in the band 2700-3400 MHz

Type of Link	Typical Tx antenna characteristics			Maximum EIRP (dBW)	Typical Environment
	Height (agl)	Directivity	Gain (dBi)		
Digital Cordless Cameras*	2 m	Omni HRP	5	0	Indoor, Outdoor (e.g. within sports stadium)
Portable link	2 m	Omni HRP		17	Outdoor event

*Note: Agreed by FM PT 41 definition of cordless cameras is as follows:

> *Cordless Camera - Handheld or otherwise mounted camera with integrated transmitter, power pack and antenna for carrying broadcast-quality video together with sound signals over short-ranges.*

In addition, it is assumed that digital ENG/OB equipment will be based on the DVB-T standard (EN 300 744).

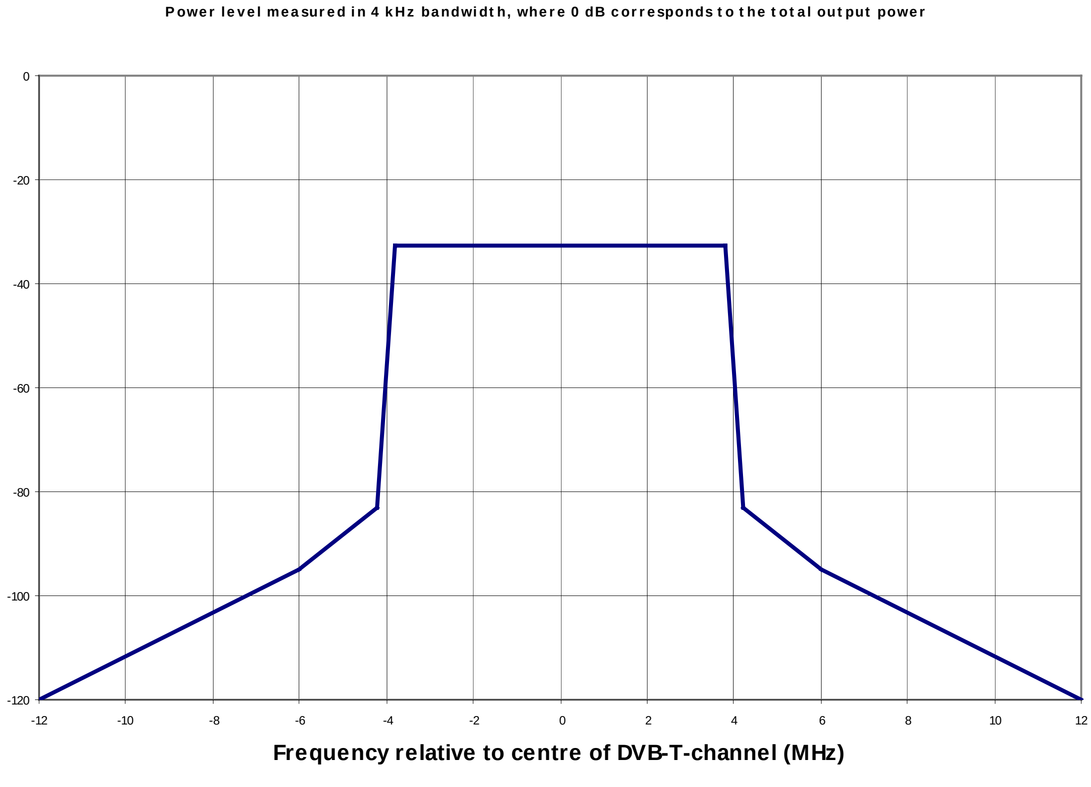

Figure A3.1: Assumed transmitting spectrum mask of 8 MHz digital ENG/OB based on DVB-T (EN 300 744)