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Spectrum Compatibility Study of Terrestrial Digital Audio Broadcasting System and the Microwave Radio Relay Links in the L-Band Using an Iterative Method

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ABSTRACT

This paper studies the spectrum compatibility of Terrestrial Digital Audio Broadcasting (T-DAB) and the microwave Radio Relay Links (RRL) in the L-Band. The two systems are using the L-Band but the systems characteristics should protect them from each other except for some cases. It is the intention of this paper to provide clear guidelines for full compatibility and therefore avoid mutual interference. The calculation of the coordination distance, that is the minimum tolerable distance between the two transmitter stations, is based upon ITU-R protection ratios and an iterative method that we attempt to detail in this paper.

Keywords: *Spectrum Compatibility, Coordination Distance, Interference, Radio wave Propagation, Protection Ratio*

1. INTRODUCTION

This document presents an iterative computation method of the coordination distance between a terrestrial DAB transmitter and RRL system in view of a possible frequency and geographical sharing. Both systems will have to share a part of the 1452-1492 MHz band allocated by WARC 92 for T-DAB transmission purposes.

Either DAB or RRL signal presents a white noise-like spectral density of 1.5 MHz bandwidth. Also, it is interesting to point out that these two digital systems use different modulations since DAB operates with D-QPSK modulation [1] and RRL with a 4-QAM modulation [2]. The detailed characteristics of both digital systems are given below.

2. TECHNICAL CHARACTERISTICS

2.1 T-DAB Characteristics in the 1.5 GHz Band

The used parameters for link budget computation purposes are summarized in table 1. They include T-DAB system parameters and receiver characteristics operating in mode II in the L-band. Also, the minimum power flux density and the minimum field strength for a typical L-band receiver are shown. The minimum C/N of interest is taken for the worst case in a Rayleigh channel for a given maximum tolerated bit error rate (BER). The thermal noise power is computed for a 6 dB receiver noise figure:

$$N = kT_0BF \tag{1}$$

where k : Boltzman's constant
T0 : Room temperature
B : Channel bandwidth
F : Receiver noise figure

TABLE I. t-dab transmitter characteristics

Operating Frequency	1453 MHz
Polarization	Linear Vertical
Channel error protection	Convolutional (R=1/2)
Channel Bandwidth	1.536 MHz
Useful Bite Rate	1152 kbit/s
Symbol Time	312 µs
Required Minimum C/N (including system and hardware implementation margins)	12 dB (Rayleigh channel)

TABLE IIIII. t-dab receiver characteristics in the l-band

Receiving Antenna Gain	0 dB
Coupling and Filter Losses	1 dB
Receiver Noise Figure	6 dB (290 K)
Thermal Noise Power	-106 dBm

2.2 RRL Characteristics in the 1.5 GHz Band

TABLE IVII. rrl transmitter characteristics

Operating Frequency	1453 MHz (co-channel with DAB) one of the IRT Band frequencies

Polarization	Vertical / Horizontal
Channel Bandwidth	1.5 GHz
Useful Bit Rate	2304 kbit/s

TABLE VV. rrl receiver characteristics in the l-band

Receiving Antenna Gain	2, 12, 16, or 21 dB
Feeder Loss	4 dB
Receiver Noise Figure	4 dB (290 K)
Thermal Noise Power	-108.2 dBm

3. COORDINATION DISTANCE CALCULATION

3.1 Calculation Assumptions

Up till now, there is no agreement on a prediction method for terrestrial broadcast services in the 1.5 GHz band. Among the suggested propagation models within EBU and CEPT, an empirical model [4], based on the existing ITU-R Recommendation 370 and corrected by extrapolations, can be preliminary used. In this document, this model will be referred to as "CCIR extrapolated" whose mathematical formulation is based upon correction factors applied to the well-known CCIR 370 Recommendation model. Corrections are valid for median fields and for 1 and 50 % of time.

RRL transmitter antenna heights above ground level are reasonably low compared with the existing broadcast transmitters. Hence, a value of 30 m is taken as a test-value and, obviously, one could experience a set of various antenna heights using the same utilized formulations.

3.2 T-DAB and RRL Transmission Parameters

Let us use typical values for both T-DAB and IRT transmission parameters according to field trials [5] previously made for T-DAB and IRT relays currently used in France [2]. Consequently, IRT transmitter antenna heights above ground level are reasonably low compared with the existing broadcast transmitters. Hence, a value of 30 m is taken as a test-value and, obviously, one could experience a set of various antenna heights using the same formulations adopted above.

TABLE V. T-DAB and RRL transmitter parameters

	T-DAB Transmitter	**RRL Transmitter (Main Lobe)**
ERP	30 dB(W)	2 *, 12, 16, or 21 dB(W)
Antenna Height	150 m	30 m
Antenna Gain	5 dB	2 *, 12, 16, or 21 dB * Omnidirectional

3.3 Interference from RRL to T-DAB Receiver

T-DAB emissions are assumed to be omnidirectional and IRT emissions directive except for one situation (omnidirectional antenna). Hence, for the computation of the coordination distance, two main cases are identified:

3.3.1 RRL Main Lobe Oriented to T-DAB Transmitter

This is obviously the worst case situation for T-DAB reception and it can be illustrated by the figure below (figure 1).

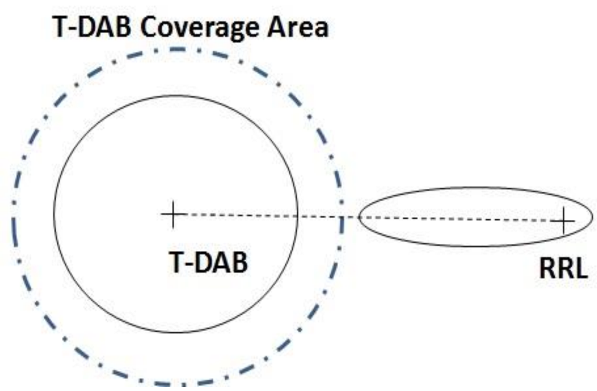


Figure 1: Interference scenario from RRL to T-DAB

3.3.2 RLL Main Lobe not Oriented to T-DAB Transmitter

T-DAB transmitter can be situated so as the main lobe of the IRT transmitter does not radiate its maximum power in the direction of T-DAB. This situation is illustrated in figure 2 and consequently, calculation of the coordination distance should take into account of the amount of power received from the RRL for a given angle according to figure 2. This could be the general case and the 0° azimuth situation (see figure 1) can be taken as a particular case. However, this particular case represents the worst case situation that is the reason why it is quite interesting to treat it in a first step.

The knowledge of the radiation antenna pattern allows the computation of the coordination distances for different antenna categories as described above. Furthermore, the use of ITU-R Recommendation [3], and for the same radiated powers, one could yield the different ERPs for any azimuth. Hence, for the sake of testing the above described method, a single and unique value for the azimuth seems to be sufficient to compute the amount of power radiated in the T-DAB direction. Hence, a value of 90° is considered applying a set of antenna gains given according to ITU-R Rec.699, and for the previously studied antennas we obtain the values of : 6 dB (side lobe of Yagi), 3 dB (Dish).

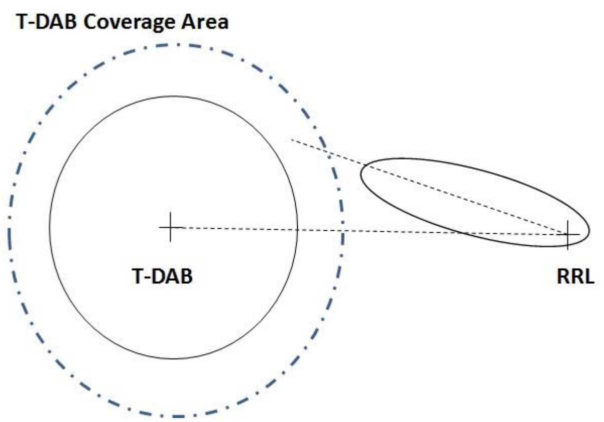
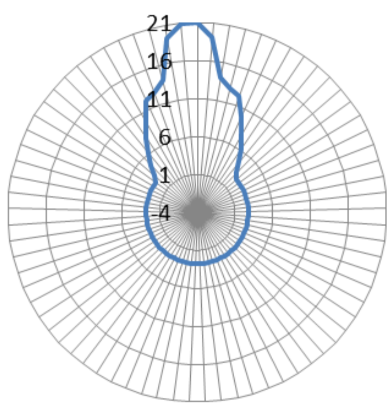


Figure 2: Interference scenario from RRL to T-DAB (main lobe not pointing to the T-DAB Receiver)



The required coordination distance for a possible frequency and geographical sharing between the two digital systems can be computed by firstly determining the T-DAB transmitter coverage radius. Afterwards, a good reception condition at the edge of T-DAB coverage area (computed using the required protection ratio relative to the thermal noise) when an RRL transmission is present can be written. This would determine, by means of an iterative calculation, the required distance between the limit of T-DAB coverage area and the RRL transmitter position.

The achievement of such a calculation requires the knowledge of propagation models for respectively 1% (interfering power) and 50 % (wanted power) of the time. As it has been previously noted, an extrapolated propagation model of the well-known CCIR 370 propagation model is available. The extrapolation is simply based on the addition of two correcting factors depending on the % of time (interfering or wanted fields). Hence, if D is the distance in km the correction gives:

$$-0.05D \text{ for 50 \% of the time}$$

$$-0.28\sqrt{D} \text{ for 1 \% of the time}$$

Also, for T-DAB mobile reception a correction factor of -13 dB for a 1.5 m receiver antenna height has been taken into account for the computation of the wanted and unwanted fields. Hence, noting D and Ht respectively the distance and the transmitter effective antenna height, the conversion of the field into received power in dBm can be written as follows:

$$C(dBm) = -20\log(f) + E50(ERP, D, Ht) - 0.05D - 77.3 - 13 \quad (2)$$

Where

$E50(ERP, D, Ht)$: Median field strength in dB(μV/m) calculated by means of the CCIR370 model for a receiving antenna height of 10 m and for 50 % of the time.

Similarly, for the interfering power, one could write the following:

$$I(dBm) = -20\log(f) + E1(EIRP, D, Ht) - 0.28\sqrt{D} - 77.3 - 13 \quad (3)$$

Where

$E1(ERP, D, Ht)$: Median field strength in dB(μV/m) calculated by means of the CCIR370 model for a receiving antenna height of 10 m and for 1 % of the time. D and f are the distance in kilometres and the frequency in MHz respectively.

$$ERP = P_{output} + G_t - L_{cc}$$

EIRP : Effective Radiated Power, L_{cc} is the cable and coupling losses. G_t being the transmitter antenna gain. Applying this enables the computation of the coverage radius of T-DAB transmitter using the abovementioned parameters.

For the sake of simplicity, we assume that the variability of both DAB and RRL field strengths is log-normal with a standard deviation of about 5 dB. Hence, this assumption allows the use of the stochastic considerations [6] made for the computation of the probability for which C/(N+I) is greater than the system operation threshold (namely the minimum C/N) in view of protecting the DAB system from an I interferer whose probability density function behaves as a log-normal law with a standard deviation of 5 dB. Needless to say that the presence of the thermal noise N will also be taken into account, bearing in mind that its contribution is seemingly less severe than in VHF band [7].

The previously carried out work [6] on the stochastic considerations of the field variability aiming to protect DAB against a log-normally distributed interferer yields a set of parametric curves imposing the conditions of having a comfortable C/(N+I) for good DAB reception. These curves take into account the normalized levels of I/N for a given % of locations to keep C/(N+I) above the DAB system operation threshold (i.e. C/N). A margin of 1 dB above the minimum required of C/N (say Th) has been taken for the computation of the coverage radius of T-DAB transmitter. This would give, according to the set of the parametric curves [6], a corresponding value for (I/N - Th) of -7 dB. Hence, the link budget for both the wanted and the interferer can be recast in a much condensed form in table 4. Coordination distance is then calculated by summing up the coverage radius and the distance from which the edge of coverage area the RRL transmitter has to be situated. This distance is nothing but the result of the iterative distance computed for the I power for which the condition I/N - Th = -7 dB is satisfied.

TABLE VI. interference link budget including thermal noise

T-DAB (wanted)	RRL (unwanted)
C/N - Th = 1 dB	I/N - Th = -7 dB
C = - 94 dBm	I = - 101 dBm

The knowledge of both C and I as mentioned in TABLE VI enables the calculation by iteration the T-DAB coverage radius, the RRL transmitter position referring to the limit of T-DAB coverage area fixed by the coverage radius and afterwards the desired coordination distance. It is obvious then to note that the coordination distance depends upon the RRL transmitter antenna gain. Results are summarized in TABLE VII and TABLE VIII according to the two studied transmitters' parameters.

TABLE VII. interference link budget including thermal noise

T-DAB Coverage Range	RRL to T-DAB Coverage limit	RRL Transmitting Antenna Gain
14.7 km	12.5 km	2 dB (Omni)
14.7 km	19.7 km	12 dB (Horn)
14.7 km	23.8 km	16 dB (Yagi)
14.7 km	30.3 km	21 dB (Dish)
Coordination Distance		
27.2 km (Omni)		
34.4 km (Horn)		
38.5 km (Yagi)		
45.0 km (Dish)		

And in the same manner, results of calculation are shown for case b) in TABLE VIII. The results are for the same previously made assumptions, namely, for different antenna gains and a fixed azimuth angle of 90°. Antenna heights are respectively 150 m and 30 m for T-DAB transmission and RRL radio relay links.

TABLE viii. interference link budget including thermal noise

T-DAB Coverage Radius	RRL to T-DAB Coverage limit	RRL Transmitting Antenna Gain (90°)
14.7 km	14.9 km	6 dB (Side lobe)
14.7 km	13.1 km	3 dB (Dish)
Coordination Distance		
29.6 km (Side lobe)		
27.8 km (Dish)		

3.4 Interference from T-DAB to RRL Receiver

Insuring the complete coordination and geographical sharing between the two services requires the study of the effect of interference from T-DAB to RRL. Subsequently, we study the case where RRL behaves as the receiver and T-DAB as an additive interferer (including the thermal noise N). Also, two different cases can be distinguished where the RRL antennas are either directive or omnidirectional. Indeed, RRL antenna gains are used for receiving or transmitting situations.

In the case where RRL is subjected to T-DAB emissions, the computation of the coordination distance requires the knowledge of the maximum tolerable power flux density given by the following [8]:

$$\mathrm{MaxPFD}\left(\frac{\frac{\mathrm{dBW}}{\mathrm{m}^2}}{4\mathrm{kHz}}\right) = \mathrm{Noise}\left(\frac{\mathrm{dBW}}{4\mathrm{kHz}}\right) + \mathrm{FL} - \mathrm{G} + \mathrm{PD} + 20\log f - 38.6$$

where

Noise : Receiver noise in 4kHz for a 4 dB receiver noise figure.

FL : Feeder loss (4 dB)

G : RRL antenna gain in the T-DAB transmitter direction (dBi)

f : Frequency (MHz)

PD : Polarisation discrimination (dB)

Subsequently, this computed maximum PFD, for coordination purpose, must equal the PFD given by the presence of T-DAB emission that can also be written as:

$$PFD\left(\frac{\frac{dBW}{m^2}}{4kHz}\right) = ERP(1.5MHz) - 17.9 + E1(D, H_t) - 0.28\sqrt{D}\text{-}146$$

Where E1(D, Ht) : The interferer median field strength due to T-DAB transmitter computed by means of the ITU-R Rec. 370. Bearing in mind that EIRP must be computed in a bandwidth of 4 kHz, which thus requires the subtraction of 17.9 dB to be considered from the 1.5 MHz bandwidth EIRP.

The calculation of the coordination distance is then achieved using a similar iterative process used in the case where the RRL interferes on T-DAB. Indeed, the iterative procedure deals with PFDs instead of field strengths as it has been the case previously studied (i.e. T-DAB subjected to the RRL emission). However, no receiver antenna height correction is used since RRL receiver antenna height exceeds generally 10 m above ground level which is quite easier to handle using the "extrapolated CCIR370" model. Results are shown in ANNEX1 and ANNEX2.

The cross polarisation discrimination effect is also considered in this document. A value of PD = 16 dB is taken according to reference [9] for Digital System as described in the ITU-R Document.

4. CALCULATION RESULTS

4.1 RRL to T-DAB Receiver

According to the above mentioned statements we distinguish four cases

Case 1: Omnidirectional RRL Transmit Antenna

The calculation results are illustrated in the figure 3 below:

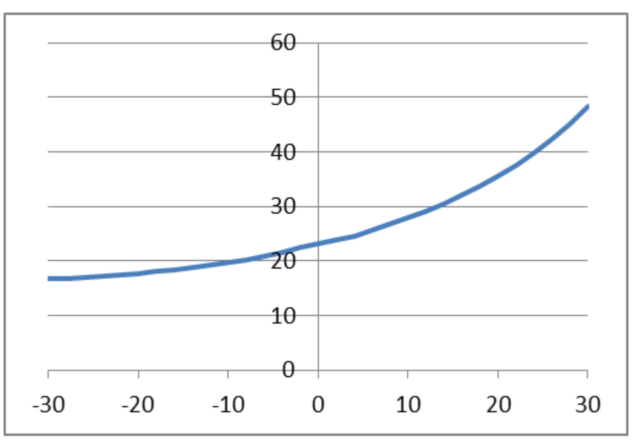


Figure 3: Coordination distance versus Output Power Ratios RRL/T-DAB for Omnidirectional RRL Antenna

It is clearly shown from figure 3 that the coordination distance for equal powers (T-DAB and RRL) is about 23 km using an ominidirectional RRL antenna. The higher is the ratio the larger is the coordination distance, which goes up to 50km when the difference in powers is about 30 dB.

Case 2: Horn RRL Transmit Antenna

The calculation results are illustrated in the figure 4 below:

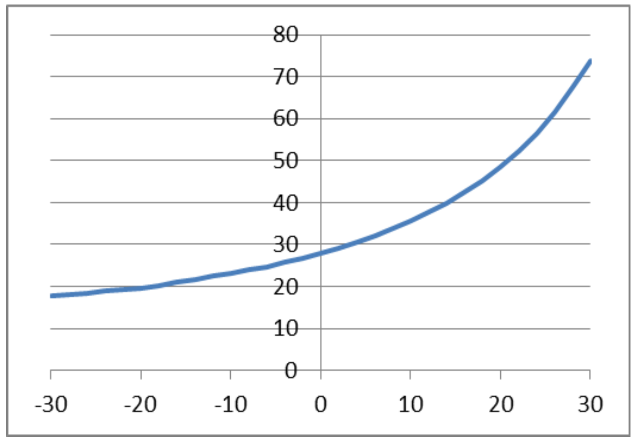


Figure 4: Coordination distance versus Output Power Ratios RRL/T-DAB for Horn RRL Antenna

The results suggest an increase in the coordination distance as the gain is much higher than the omnidirectional case, which is quite expectable.

Case 3: Yagi RRL Transmit Antenna

The calculation results are illustrated in the figure 5 below:

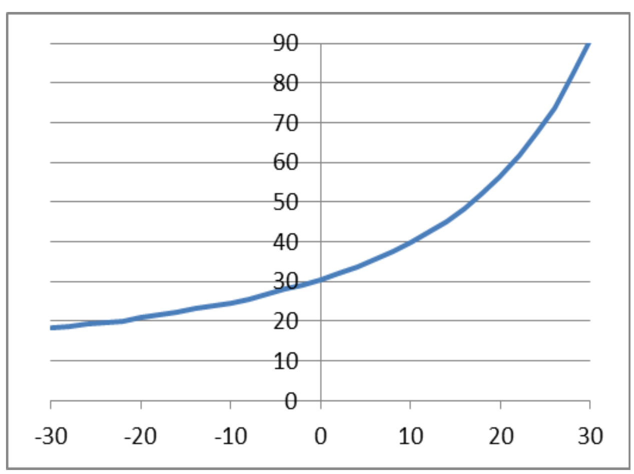


Figure 5: Coordination distance versus Output Power Ratios RRL/T-DAB for Yagi RRL Antenna

In this case the equal power situation suggests a coordination distance of 30 km. We notice again an increase of this coordination distance of about 15km between the Yagi and the Horn antenna cases when the difference in powers reaches 30 dB.

Case 4: Dish RRL Transmit Antenna

The calculation results are illustrated in the figure 6 below:

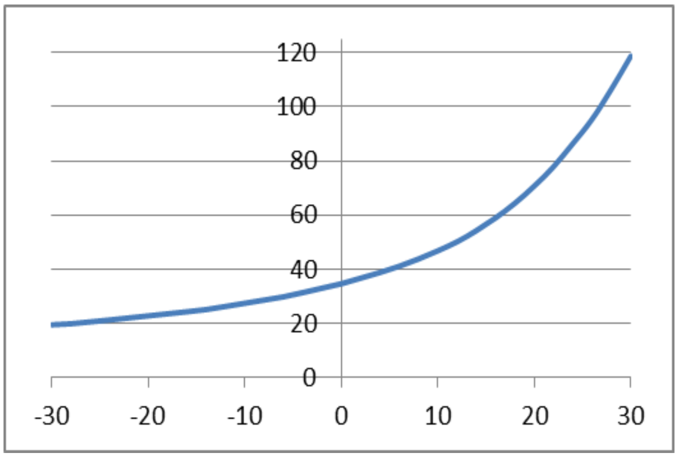


Figure 6: Coordination distance versus Output Power Ratios RRL/T-DAB for Dish RRL Antenna

In this fourth case we notice a substantial increase in the coordination distance for 30 dB power difference. However, the value of the coordination distance does not change a lot for equal powers.

4.2 T-DAB to RRL Receiver

This part shows the results for the T-DAB interfering on the RRL with and without crossed polarisation.

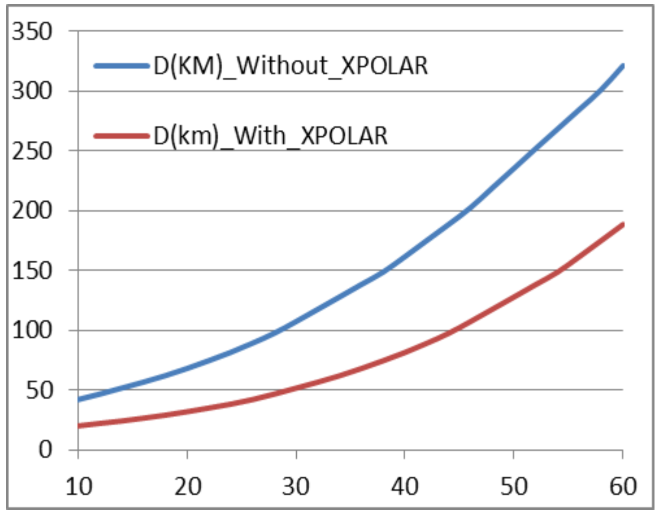


Figure 7: Coordination distance versus T-DAB ERP, Omnidirectional RRL Antenna

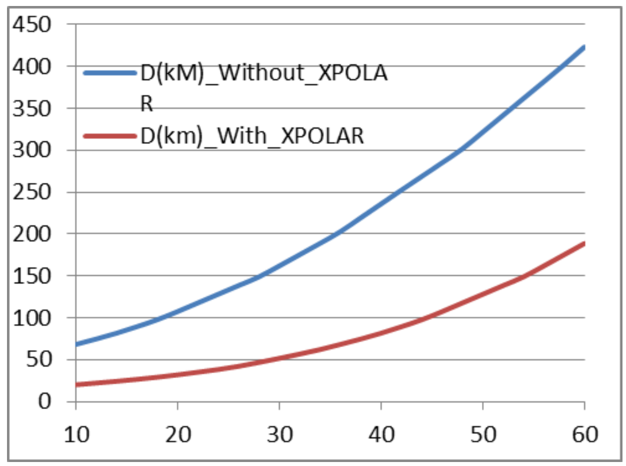


Figure 8: Coordination distance versus T-DAB ERP, Horn RRL Antenna

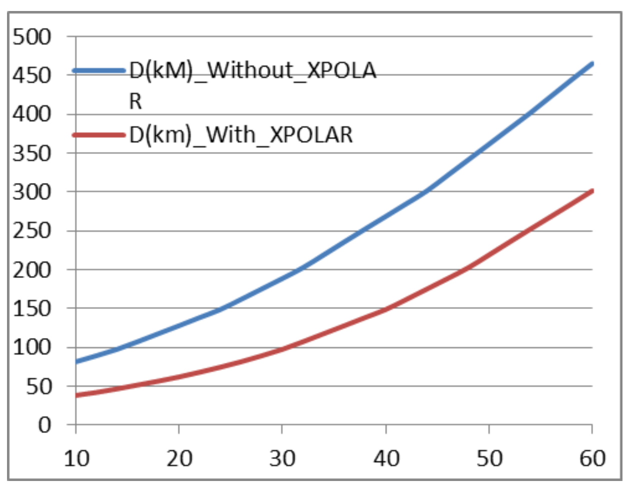


Figure 9: Coordination distance versus T-DAB ERP, Yagi RRL Antenna

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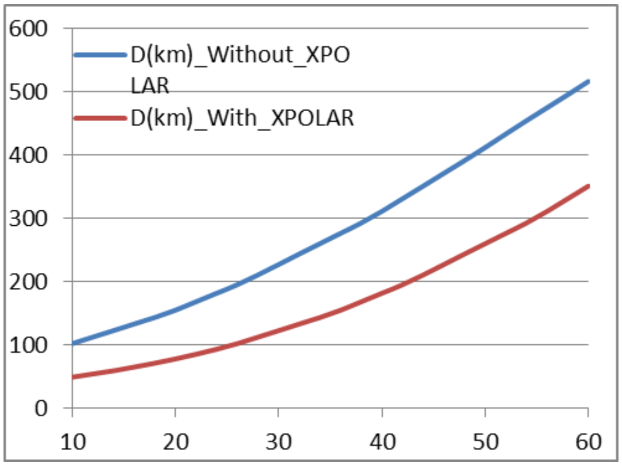

Figure 10: Coordination distance versus T-DAB ERP, Dish RRL Antenna

It is noticed that the cross polarisation markedly reduces the coordination distance. The difference is non-linear as it can be seen from figure 7. Therefore, to keep this coordination distance small one needs to reduce the T-DAB emission power, especially in the case where this T-DAB transmitter is in urban environment. Fortunately the RRL are usually deployed and installed on hills and mountains in rural areas.

5. CONCLUSION

It can be noticed that RRL to T-DAB interference is less severe than the T-DAB to RRL interference (see figures 3,4,5 and 6). Consequently, the coordination distance is thus taken for the worst case situation (i.e. T-DAB/RRL interference case of Section B) which imposes larger distances for T-DAB broadcasters insuring then the protection of the two systems.

The use of cross polarized antennas decreases considerably the coordination distance as it can be noticed from figures 7, 8, 9, and 10. Cross polarisation plays a very important role especially when ERPs are very large.

Furthermore, for adjacent-channel T-DAB with the RRL, one would take into account the shoulder level (out of band radiation) and use the same framework used up till now through this document.

As a final remark, frequency and geographical sharing between T-DAB and RRL is quite feasible provided that a given coordination distance is allowed. This coordination distance depends upon a set of parameters given by the document.

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