European Radiocommunications Committee (ERC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

ADJACENT BAND COMPATIBILITY OF 400 MHZ TETRA AND ANALOGUE FM PMR – AN ANALYSIS COMPLETED USING A MONTE CARLO BASED SIMULATION TOOL

Vilnius, June 2000

EXECUTIVE SUMMARY

The digital Terrestrial Enhanced Trunked Radio (TETRA) standard for second generation PMR / PAMR radio systems has been developed by the European Telecommunications Standards Institute (ETSI). A large number of the frequency bands proposed for TETRA are adjacent to bands currently used by FM systems. This study provides an analysis of TETRA and FM compatibility. All interference scenarios between TETRA and FM are identified and simulated and the required minimum frequency separations determined. The simulation tool used is one based upon the statistical Monte Carlo methodology developed within CEPT.

The scenarios identified include those belonging to non co-sited TETRA and FM systems, co-sited TETRA and FM systems and TETRA direct mode. In each case various investigations are made into the effect of interferer density, minimum frequency separation, band allocation size and where appropriate power control.

The following conclusions are drawn from the study :

- under normal operating conditions TETRA and FM bands are able to coexist without guard bands in the same way that two FM operators are able to coexist without guard bands.

- in special circumstances where there is a very high density of active users e.g. security at a large sports event, then care must be taken to minimize levels of interference. Frequency coordination between TETRA and FM operators at special events could help relieve any problems. Additional filtering in base station transmitters and receivers is also an effective method for controlling levels of interference.

- co-siting TETRA and FM base stations reduces levels of interference in all scenarios except mobile to mobile and of course base to base. Frequency coordination between TETRA and FM operators will make co-siting easier.

- TETRA direct mode does not cause high levels of interference to the general FM user. Levels of interference are greater for an FM user who is involved in the direct mode group e.g. at the scene of an accident where the police and fire services are using TETRA but the ambulance service is using FM. The introduction of power control in TETRA direct mode would alleviate any interference problems but simulations have not been completed to illustrate this.

Where coordination is required as systems are rolled out across Europe, it should be done on a case by case basis using site-engineering practices.

This study provides simulation results for general 400 MHz TETRA and FM compatibility. Further work would be required to model specific scenarios within CEPT member states.

INDEX TABLE

1 SCOPE

This report provides a guide to allocating TETRA channels adjacent to existing analogue FM channels. The study considers all interference scenarios between the two systems and identifies those, which are most critical. Various user densities are chosen to model different geographic areas. The minimum frequency separation for an acceptable level of interference is determined. The study concentrates upon frequency allocations in the 400 MHz band.

2 INTRODUCTION

2.1 Background

The digital Terrestrial Enhanced Trunked Radio (TETRA) standard for second generation PMR / PAMR radio systems has been developed by the European Telecommunications Standards Institute (ETSI), ETS 300394 and its derivatives. TETRA equipment is now available from various manufacturers and demand is growing. Before TETRA radio systems can be deployed, regulators must allocate sets of channels, which can be used by the TETRA system. These channels will occupy spectrum adjacent to existing systems, which should not be affected by the introduction of TETRA and conversely should not affect TETRA. In many cases the adjacent systems will be first generation analogue FM systems. This study investigates adjacent band compatibility issues between TETRA and analogue FM.

2.2 Objectives

The objectives of this study are to :

- Identify all interference scenarios between TETRA and analogue FM.
- Determine the critical scenarios.
- Determine minimum frequency separation requirements for acceptable levels of interference.

Levels of interference are quantified using a statistical Monte Carlo simulation tool. The tool used is based upon that specified by CEPT WG SE [1] (SEAMCAT®), and has been used previously by CEPT PT SE7 in it's studies on adjacent band compatibility issues. A brief description of the tool is given in Appendix A.

A copy of the latest version of the SEAMCAT® ,tool is available at the ERO website at http://www.ero.dk/

[1] CEPT ERC Report 68, Monte Carlo Radio Simulation Methodology, http://www.ero.dk/eroweb/seamcat/seamcat.html

3 STUDY

The first step of analyzing adjacent band compatibility between two systems is identifying all of the interference scenarios. Consider the example TETRA channel allocation illustrated in Figure 1.

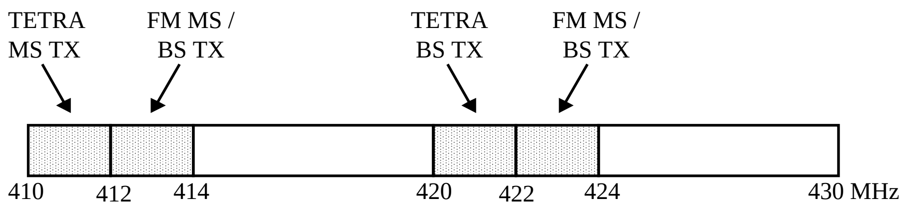

Figure 1 : An example TETRA channel allocation adjacent to FM

A mixture of FM systems are assumed to exist such that all possible combinations of radio system compatibility scenarios are considered i.e. it is assumed that FM mobile stations can both transmit and receive in both bands, as can FM base stations. This assumption allows for the consideration of all possible scenarios. In practice some of the scenarios will not occur and thus need not be taken into account. The following eight interference scenarios can be identified :

- TETRA MS interfering with FM MS
- TETRA MS interfering with FM BS
- TETRA BS interfering with FM MS
- TETRA BS interfering with FM BS
- FM MS interfering with TETRA MS
- FM MS interfering with TETRA BS
- FM BS interfering with TETRA MS
- FM BS interfering with TETRA BS

For each of these it must be considered that the FM system could be either 25 kHz, 20 kHz or 12.5 kHz. Additionally the TETRA and FM systems could be either co-sited or non co-sited. Finally TETRA direct mode (mobile to mobile) operation needs to be considered. For TETRA direct mode it is possible that there will be high user densities and currently no power control is specified.

This leads to the following report format :

4. Non Co-sited Systems
   4.1 The Effect of TETRA upon FM
   4.2 The Effect of FM upon TETRA
5. Co-sited Systems
   5.1 The Effect of TETRA upon FM
   5.2 The Effect of FM upon TETRA
6. TETRA Direct Mode
   6.1 The Effect of TETRA upon FM
   6.2 The Effect of FM upon TETRA

Additional sub-sections are included to investigate the effect of specific simulation parameters.

The simulations completed include the effects of interferer unwanted emissions and victim receiver blocking. Intermodulation is a third type of interference mechanism but is not included as it is believed to have less effect when considering TETRA and FM compatibility.

In some cases of unwanted emissions and receiver blocking the characteristics specified by the relevant standards have been used. This leads to a worst case result, which assumes that the transmitters and receivers have a performance equal to the specification. These and other assumed parameters are provided in Appendix B.

4 NON CO-SITED TETRA AND FM SYSTEMS

Systems, which are non co-sited use, separate masts for their base station antennas. This leads to one of the cell structures being geographically offset from the other. An illustration of this is provided in Figure 2.

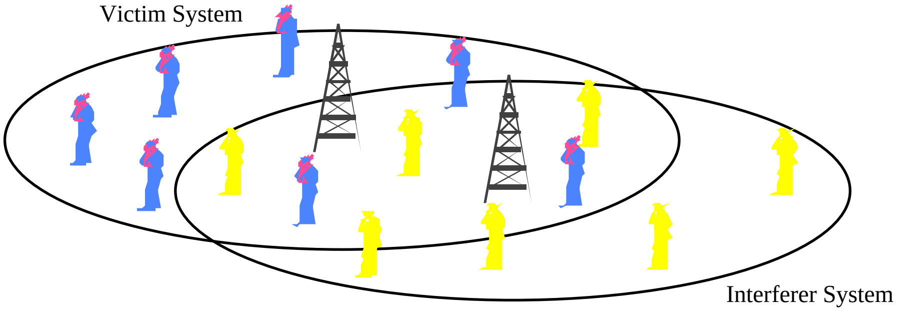

Figure 2 : A pair of non co-sited systems

Simulations have been completed to investigate the effect of active user density, minimum frequency separation, band allocation size and power control. The effect of TETRA upon FM will be investigated first followed by the effect of FM upon TETRA.

4.1 The Effect of TETRA upon FM

Four interference scenarios can be identified :

- TETRA MS interfering with an FM MS
- TETRA MS interfering with an FM BS
- TETRA BS interfering with an FM MS
- TETRA BS interfering with an FM BS.

It is assumed that the FM system is either 25 kHz, 20 kHz or 12.5 kHz. Parameters for each system are specified in Appendix B. Simulations have been completed for 25 kHz and 12.5 kHz systems. The only difference between the parameters for a 25 kHz system and a 20 kHz system is the receiver bandwidth. For a 25 kHz system the receiver bandwidth is 15 kHz whereas for a 20 kHz system it is 12 kHz. This means that levels of interference for a 20 kHz system will be slightly lower than for 25 kHz. Providing levels are acceptable for 25 kHz they will also be acceptable for 20 kHz. TETRA mobiles are assumed to be 1 Watt. Only an urban area has been considered in this report.

4.1.1 TETRA MS interfering with an FM MS

For this scenario it is possible for the interferer and victim to be very close. However transmit powers and antenna gains are lower than those belonging to a base and the wanted signal strength will be greater than that received by a base - due to uplink and downlink power budgets. In all of the simulations in this section the victim FM system is assumed to have a 7.8 km cell radius which provides a 90 % area availability.

4.1.1.1 The Effect of Active Interferer Density

The density of active interferers will be dependent upon the area being considered i.e. a sub-urban area is likely to have a lower density than an urban area. Correspondingly the level of interference in an urban area would be expected to be greater.

Figure 3 illustrates the band plan assumed for this investigation. 2 MHz of spectrum has been allocated to the uplink of TETRA and directly adjacent to this, 2 MHz has been allocated to FM.

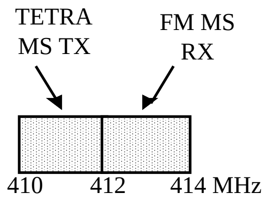

Figure 3 : The band allocations used to investigate the effect of increasing the active interferer density

Table 1 provides the levels of interference for a range of interferer densities and cell sizes. The cell sizes are based upon the density and carriers per cell assumed and are representative of those used in practice.

Active Interferer Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM MS	Probability of Interference for 12.5 kHz FM MS
0.5 / km^2	4.79 km	0.04 %	0.04 %
1 / km^2	3.39 km	0.08 %	0.08 %
1 / km^2	3.91 km	0.08 %	0.09 %
2 / km^2	2.39 km	0.15 %	0.15 %
2 / km^2	2.75 km	0.15 %	0.16 %
4 / km^2	1.95 km	0.26 %	0.28 %
5 / km^2	1.75 km	0.31 %	0.33 %
10 / km^2	1.24 km	0.50 %	0.52 %

Table 1 : The probability of interference for an FM mobile amongst a population of TETRA mobiles for a range of active interferer densities

The level of interference increases as the density of active interferers increases. When the interferer density is fixed but the number of carriers per cell is increased - allowing the TETRA cell size to increase, then the level of interference increases slightly due to power control being used to a lesser extent.

4.1.1.2 The Effect of Minimum Carrier Separation

For this investigation the same size bands as in the previous section are allocated but in this case the minimum carrier separation between the TETRA and FM bands is varied. This is illustrated in Figure 4.

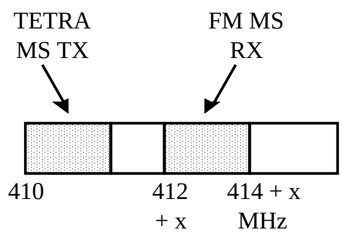

Figure 4 : The band allocations used to investigate the effect of increasing the minimum frequency separation

Table 2 provides the levels of interference for a range of minimum carrier separations. The TETRA active user density is fixed at 4 / km^2 and the TETRA cell radius at 1.95 km.

Minimum Carrier Separation	**Active Interf. Density**	**TETRA Cell Radius**	**Probability of Interference for 25 kHz FM MS**	**Probability of Interference for 12.5 kHz FM MS**
25 kHz	4 / km^2	1.95 km	0.26 %	0.28 %
50 kHz	4 / km^2	1.95 km	0.26 %	0.28 %
100 kHz	4 / km^2	1.95 km	0.26 %	0.28 %
250 kHz	4 / km^2	1.95 km	0.26 %	0.28 %
500 kHz	4 / km^2	1.95 km	0.26 %	0.28 %

Table 2 : The probability of interference for an FM mobile amongst a population of TETRA mobiles for a range of minimum carrier separations

The probabilities of interference remain constant as the minimum carrier separation is increased. This is because the TETRA out-of-band emissions characteristic is flat for frequency offsets above 250 kHz.

The probabilities of interference calculated above are for an FM mobile victim who is able to use any channel across the FM band. It is also of interest to repeat the previous investigation for an FM victim who is restricted to using the FM channel closest to the TETRA band. This is illustrated in Figure 5.

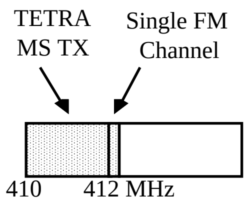

Figure 5 : The band allocations used to investigate the effect of increasing the minimum carrier separation when the victim has only a single channel

Table 3 provides the levels of interference for a range of minimum carrier separations. The TETRA active user density is fixed at 4 / km^2 and the TETRA cell radius at 1.95 km.

Minimum Carrier Separation	**Active Interf. Density**	**TETRA Cell Radius**	**Probability of Interference for 25 kHz FM MS**	**Probability of Interference for 12.5 kHz FM MS**
25 kHz	4 / km^2	1.95 km	0.28 %	0.30 %
50 kHz	4 / km^2	1.95 km	0.28 %	0.29 %
100 kHz	4 / km^2	1.95 km	0.27 %	0.28 %
250 kHz	4 / km^2	1.95 km	0.26 %	0.28 %
500 kHz	4 / km^2	1.95 km	0.26 %	0.28 %

Table 3 : The probability of interference for an FM mobile amongst a population of TETRA mobiles for a range of minimum carrier separations when the victim has only a single channel

The levels of interference are slightly greater than for the case when the FM system had 2 MHz of channels allocated. This is due to the higher probability of smaller frequency offsets. There is a small decrease in the level of interference as the minimum carrier separation is increased.

4.1.1.3 The Effect of Increasing the Band Allocations

For this investigation the minimum carrier separation is maintained at its minimum and the band allocations increased. This is illustrated in Figure 6 for the case of 5 MHz band allocations.

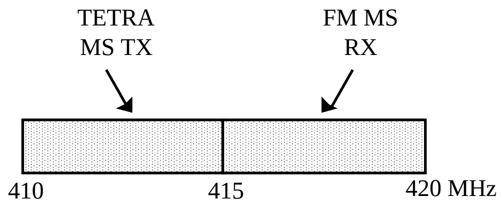

Figure 6 : One of the band allocations used to investigate the effect of increasing the band allocation size

Table 4 provides the levels of interference for a range of band allocation sizes. The TETRA active user density is fixed at 4 / km^2 and the TETRA cell size at 1.95 km.

Band Allocation Size	Active Interf. Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM MS	Probability of Interference for 12.5 kHz FM MS
2 MHz	4 / km^2	1.95 km	0.26 %	0.28 %
3 MHz	4 / km^2	1.95 km	0.26 %	0.28 %
4 MHz	4 / km^2	1.95 km	0.26 %	0.27 %
5 MHz	4 / km^2	1.95 km	0.26 %	0.27 %

Table 4 : The probability of interference for an FM mobile amongst a population of TETRA mobiles for a range of band allocation sizes

The probability of interference does not change as the band allocation is increased. This is due to the TETRA mobile station out-of-band emissions characteristic being flat above 250 kHz.

4.1.1.4 The Effect of not using Power Control for the TETRA MS

Using power control can decrease levels of interference significantly for high active user densities. This is because cell sizes are reduced and mobiles do not need to transmit at full power. This investigation determines how much the level of interference increases when power control is not used. It should be noted that in practice power control would be used otherwise cell sizes would have to be greater to constrain inter-cell co-channel interference and the corresponding system capacity would be reduced. These results are presented for information only to indicate the magnitude of the effect of power control on inter-system interference. The same simulations are completed as for the investigation into active user density in Section 4.1.1.1. Figure 7 illustrates the TETRA and FM band allocations.

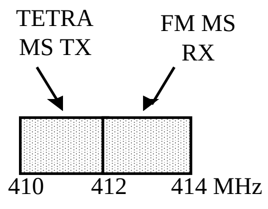

Figure 7 : The band allocations used to investigate the effect of power control

Table 5 provides the levels of interference for a range of interferer densities.

Active Interferer Density	Probability of Interference for 25 kHz FM MS	Probability of Interference for 12.5 kHz FM MS
0.5 / km^2	0.05 %	0.05 %
1 / km^2	0.09 %	0.10 %
1 / km^2	0.09 %	0.10 %
2 / km^2	0.18 %	0.19 %
2 / km^2	0.18 %	0.19 %
4 / km^2	0.36 %	0.37 %
5 / km^2	0.44 %	0.46 %
10 / km^2	0.86 %	0.89 %

Table 5 : The probability of interference for an FM mobile amongst a population of TETRA mobiles for a range of active interferer densities when power control is not used

These figures can be compared to those in Table 1. The first row of Table 1 has figures of 0.04 % and 0.04 %. The use of power control reduces the level of interference by 20 %. This is for a relatively low density of interferer. The last row of Table 1 has figures of 0.50 % and 0.52 %. In this case the use of power control reduces the level of interference by more than 40 %. This illustrates the fact that power control has a greater effect upon levels of interference for high interferer densities when the cell sizes are relatively small and mobile transmit power can be kept to a minimum.

4.1.2 TETRA MS Interfering with an FM BS

This scenario involves a population of TETRA mobile stations interfering with a victim FM base station. The interferer to victim link now includes the antenna gain of a base leading to potentially increased levels of interference. In addition the wanted signal strength arriving at the base will be less than that arriving at a mobile due to the uplink and downlink power budgets. In all of the simulations in this section the victim FM system is assumed to have a 7.8 km cell radius which provides a 90 % area availability.

4.1.2.1 The Effect of Active Interferer Density

Figure 8 illustrates the band plan assumed for this investigation. 2 MHz of spectrum has been allocated to the uplink of TETRA and directly adjacent to this, 2 MHz has been allocated to FM.

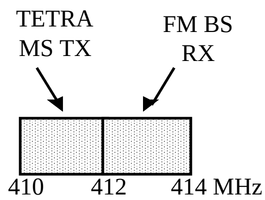

Figure 8 : The band allocations used to investigate the effect of increasing the active interferer density

Table 6 provides the levels of interference for a range of interferer densities and cell sizes. The cell sizes are based upon the density and carriers per cell assumed and are representative of those used in practice.

Active Interferer Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM BS	Probability of Interference for 12.5 kHz FM BS
0.5 / km^2	4.79 km	0.51 %	0.58 %
1 / km^2	3.39 km	0.96 %	1.10 %
1 / km^2	3.91 km	0.98 %	1.13 %
2 / km^2	2.39 km	1.65 %	1.89 %
2 / km^2	2.75 km	1.74 %	2.00 %
4 / km^2	1.95 km	2.88 %	3.28 %
5 / km^2	1.75 km	3.28 %	3.77 %
10 / km^2	1.24 km	4.74 %	5.41 %

Table 6 : The probability of interference for an FM base station amongst a population of TETRA mobiles for a range of active interferer densities

The level of interference increases as the density of active interferers increases. When the interferer density is fixed but the number of carriers per cell is increased - allowing the TETRA cell size to increase, then the level of interference increases slightly due to power control being used to a lesser extent.

4.1.2.2 The Effect of Minimum Carrier Separation

Section 4.1.1.2 showed that the level of interference does not change as the minimum carrier separation between the 2 MHz band allocations is increased. If however the FM victim is restricted to using the FM channel closest to the TETRA band then there is a reduction in the level of interference as the carrier separation is increased. This scenario is illustrated in Figure 9.

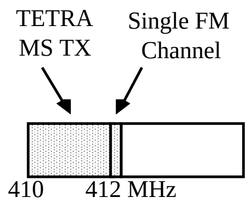

Figure 9 : The band allocations used to investigate the effect of increasing the minimum carrier separation when the victim has only a single channel

Table 7 provides the levels of interference for a range of minimum carrier separations. The TETRA active user density is fixed at 4 / km^2 and the TETRA cell size at 1.95 km.

Minimum Carrier Separation	Active Interf. Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM BS	Probability of Interference for 12.5 kHz FM BS
25 kHz	4 / km^2	1.95 km	3.12 %	3.55 %
50 kHz	4 / km^2	1.95 km	3.06 %	3.48 %
100 kHz	4 / km^2	1.95 km	2.97 %	3.38 %
250 kHz	4 / km^2	1.95 km	2.86 %	3.27 %
500 kHz	4 / km^2	1.95 km	2.86 %	3.27 %

Table 7 : The probability of interference for an FM base station amongst a population of TETRA mobiles for a range of minimum carrier separations when the victim has only a single channel

The levels of interference are slightly greater than for the case when the FM system had 2 MHz of channels allocated. This is due to the higher probability of smaller frequency offsets. There is a decrease in the level of interference as the minimum carrier separation is increased.

4.1.2.3 The Effect of Increasing the Band Allocations

Section 4.1.1.3 showed that the level of interference did not change as the allocated bands were increased from 2 MHz to 5 MHz.

4.1.2.4 The Effect of not using Power Control for the TETRA MS

Using power control can decrease levels of interference significantly for high active user densities. This is because cell sizes are reduced and mobiles do not need to transmit at full power. This investigation determines how much the level of interference increases when power control is not used. It should be noted that in practice power control would be used otherwise cell sizes would have to be greater to constrain inter-cell co-channel interference and the corresponding system capacity would be reduced. These results are presented for information only to indicate the magnitude of the effect of power control on inter-system interference. The same simulations are completed as for the investigation into active user density in Section 4.1.2.1. Figure 10 illustrates the TETRA and FM band allocations.

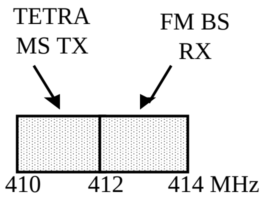

Figure 10 : The band allocations used to investigate the effect of power control

Table 8 provides the levels of interference for a range of interferer densities.

Active Interferer Density	Probability of Interference for 25 kHz FM BS	Probability of Interference for 12.5 kHz FM BS
0.5 / km^2	0.54 %	0.63 %
1 / km^2	1.09 %	1.24 %
1 / km^2	1.09 %	1.26 %
2 / km^2	2.11 %	2.39 %
2 / km^2	2.12 %	2.40 %
4 / km^2	3.98 %	4.55 %
5 / km^2	4.91 %	5.51 %
10 / km^2	8.71 %	9.73 %

Table 8 : The Probability of Interference for an FM base station amongst a Population of TETRA Mobiles for a Range of Active Interferer Densities when Power Control is not used

These figures can be compared to those in Table 6. The first row of Table 6 has figures of 0.51 % and 0.58 %. The use of power control reduces the level of interference by 5 %. This is for a relatively low density of interferer. The last row of Table 6 has figures of 4.74 % and 5.41 %. In this case the use of power control reduces the level of interference by more than 40 %. This illustrates the fact that power control has a greater effect upon levels of interference for high interferer densities when the cell sizes are relatively small and mobile transmit power can be kept to a minimum.

4.1.3 TETRA BS interfering with an FM MS

For this scenario the density of interferers is relatively low. However, the transmit power is greater and no power control is used. The victim is receiving from a base station and will benefit from the downlink power budget. In all of the simulations in this section the victim FM system is assumed to have a 7.8 km cell radius which provides 90 % area availability.

4.1.3.1 The Effect of Active Interferer Density

The density of active interferers will be dependent upon the area being considered i.e. a sub-urban area is likely to have a lower density than an urban area. Correspondingly the level of interference in an urban area would be expected to be greater.

Figure 11 illustrates the band plan assumed for this investigation. 2 MHz of spectrum has been allocated to the downlink of TETRA and directly adjacent to this, 2 MHz has been allocated to FM.

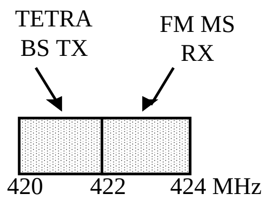

Figure 11 : The band allocations used to investigate the effect of increasing the active interferer density

Table 9 provides the levels of interference for a range of interferer densities. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Active Interferer Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM MS	Probability of Interference for 12.5 kHz FM MS
0.01 / km^2	5.64 km	0.02 %	0.02 %
0.02 / km^2	3.99 km	0.04 %	0.05 %
0.05 / km^2	2.52 km	0.10 %	0.11 %
0.10 / km^2	1.78 km	0.21 %	0.22 %
0.20 / km^2	1.26 km	0.41 %	0.44 %

Table 9 : The probability of interference for an FM mobile amongst a population of TETRA base stations for a range of active interferer densities

The level of interference increases as the density of active interferers increases. The percentage increase is greater than when the interferers were mobile stations because TETRA base stations use no power control.

4.1.3.2 The Effect of Minimum Carrier Separation

For this investigation the same size bands as in the previous section are allocated but in this case the minimum frequency separation between the TETRA and FM bands is varied. This is illustrated in Figure 12.

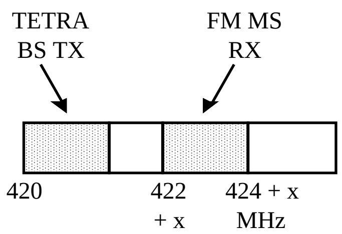

Figure 12 : The band allocations used to investigate the effect of increasing the minimum carrier separation

Table 10 provides the levels of interference for a range of minimum carrier separations. The TETRA base station density is fixed at 0.05 / km^2. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Minimum Carrier Separation	Active Interf. Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM MS	Probability of Interference for 12.5 kHz FM MS
25 kHz	0.05 / km^2	2.52 km	0.10 %	0.11 %
50 kHz	0.05 / km^2	2.52 km	0.10 %	0.11 %
100 kHz	0.05 / km^2	2.52 km	0.10 %	0.11 %
250 kHz	0.05 / km^2	2.52 km	0.10 %	0.11 %
500 kHz	0.05 / km^2	2.52 km	0.10 %	0.11 %

Table 10 : The probability of interference for an FM mobile amongst a population of TETRA base stations for a range of minimum carrier separations

The probabilities of interference remain constant as the minimum carrier separation is increased. These probabilities are for an FM victim who is able to use any channel across the FM band. It is also of interest to repeat the investigation for an FM victim who is restricted to using the FM channel closest to the TETRA band. This is illustrated in Figure 13.

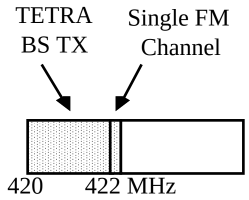

Figure 13 : The band allocations used to investigate the effect of increasing the minimum carrier separation when the victim has only a single channel

Table 11 provides the levels of interference for a range of minimum frequency separations. The TETRA base station density is fixed at 0.05 / km^2. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Minimum Carrier Separation	Active Interf. Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM MS	Probability of Interference for 12.5 kHz FM MS
25 kHz	0.05 / km^2	2.52 km	0.15 %	0.16 %
50 kHz	0.05 / km^2	2.52 km	0.13 %	0.14 %
100 kHz	0.05 / km^2	2.52 km	0.12 %	0.13 %
250 kHz	0.05 / km^2	2.52 km	0.10 %	0.11 %
500 kHz	0.05 / km^2	2.52 km	0.10 %	0.11 %

Table 11 : The probability of interference for an FM Mobile amongst a population of TETRA base stations for a range of minimum carrier separations when the victim has only a single channel

The level of interference is greater than for the case when the FM system had 2 MHz of channels allocated. This is due to the higher probability of smaller frequency offsets. There is a decrease in the level of interference as the minimum carrier separation is increased. At minimum carrier separations of 250 kHz and 500 kHz the levels of interference are reduced back to those in Table 10.

4.1.3.3 The Effect of Increasing the Band Allocations

For this investigation the minimum carrier separation is maintained at its minimum and the band allocations increased. This is illustrated in Figure 14 for the case of 5 MHz band allocations.

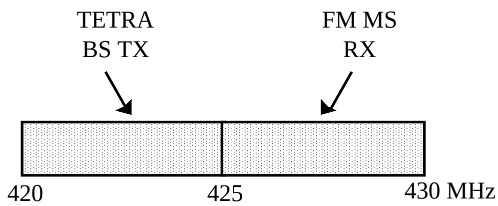

Figure 14 : One of the band allocations used to investigate the effect of increasing the band allocation size

Table 12 provides the levels of interference for a range of band allocation sizes. The TETRA base station density is fixed at 0.05 / km^2. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Band Allocation Size	Active Interf. Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM MS	Probability of Interference for 12.5 kHz FM MS
2 MHz	0.05 / km^2	2.52 km	0.10 %	0.11 %
3 MHz	0.05 / km^2	2.52 km	0.10 %	0.11 %
4 MHz	0.05 / km^2	2.52 km	0.10 %	0.11 %
5 MHz	0.05 / km^2	2.52 km	0.10 %	0.11 %

Table 12 : The probability of interference for FM mobiles amongst a population of TETRA base stations for a Range of Band Allocation Sizes

The probability of interference does not change as the band allocation is increased.

4.1.4 TETRA BS Interfering with an FM BS

For this scenario the density of interferers is relatively low. However, the transmit power is greater and no power control is used. In addition the interferer to victim path includes two high gain antennas and the victim is receiving from a mobile. In all of the simulations in this section the victim FM system is assumed to have a 7.8 km cell radius which provides 90 % area availability.

4.1.4.1 The Effect of Active Interferer Density

Figure 15 illustrates the band plan assumed for this investigation. 2 MHz of spectrum has been allocated to the downlink of TETRA and directly adjacent to this, 2 MHz has been allocated to FM.

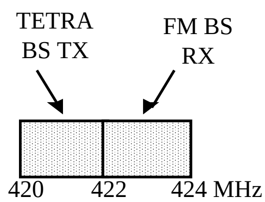

Figure 15 : The band allocations used to investigate the effect of increasing the active interferer density

Table 13 provides the levels of interference for a range of interferer densities. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Active Interferer Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM BS	Probability of Interference for 12.5 kHz FM BS
0.01 / km^2	5.64 km	1.71 %	2.09 %
0.02 / km^2	3.99 km	3.29 %	4.00 %
0.05 / km^2	2.52 km	7.31 %	8.69 %
0.10 / km^2	1.78 km	12.55 %	14.64 %
0.20 / km^2	1.26 km	20.09 %	22.93 %

Table 13 : The probability of interference, for an FM base station, amongst a population of TETRA base stations, for a range of active interferer densities

The level of interference increases significantly as the density of active interferers increases. The percentage increase is greater than when the interferers were mobile stations because TETRA base stations use no power control and the antenna gain is greater. It should be noted that the higher densities of TETRA base stations represent hot spots. A typical urban TETRA cell will have a radius of approximately 4 km corresponding to a density of 0.02 %. Using additional filtering in the transmitting or receiving base can reduce the levels of interference in hot spots. Cavity resonators can be used in the transmitting base to reduce levels of unwanted emissions. A typical cavity resonator in the 400 MHz band can provide an attenuation of 10 dB at a frequency offset of 400 kHz. The effect of such a cavity resonator upon the levels of interference for a 25 kHz FM base station is shown in Table 14. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Active Interferer Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM BS without Cavity resonator	Probability of Interference for 25 kHz FM BS with Cavity Resonator
0.01 / km^2	5.64 km	1.71 %	0.40 %
0.02 / km^2	3.99 km	3.29 %	0.75 %
0.05 / km^2	2.52 km	7.31 %	1.78 %
0.10 / km^2	1.78 km	12.55 %	3.31 %
0.20 / km^2	1.26 km	20.09 %	5.93 %

Table 14 : The probability of interference, for an FM base station, amongst a population of TETRA base stations, for a range of active interferer densities

The levels of interference are reduced significantly by the additional filtering in the transmitting base station.

4.1.4.2 The Effect of Minimum Carrier Separation

For this investigation the same size bands as in the previous section are allocated but in this case the minimum carrier separation between the TETRA and FM bands is varied. This is illustrated in Figure 16.

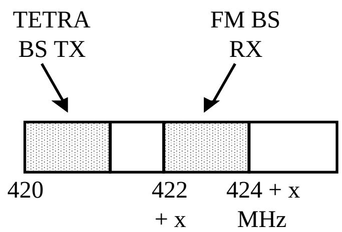

Figure 16 : The band allocations used to investigate the effect of increasing the minimum carrier separation

Table 15 provides the levels of interference for a range of minimum frequency separations. The TETRA base station density is fixed at 0.05 / km^2. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Minimum Carrier Separation	Active Interf. Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM BS	Probability of Interference for 12.5 kHz FM BS
25 kHz	0.05 / km^2	2.52 km	7.31 %	8.69 %
50 kHz	0.05 / km^2	2.52 km	7.27 %	8.65 %
100 kHz	0.05 / km^2	2.52 km	7.18 %	8.55 %
250 kHz	0.05 / km^2	2.52 km	7.09 %	8.46 %
500 kHz	0.05 / km^2	2.52 km	7.05 %	8.40 %

Table 15 : The probability of interference, for an FM base station, amongst a population of TETRA base stations, for a range of minimum carrier separations

The probabilities of interference calculated above are for an FM victim who is able to use any channel across the FM band. It is also of interest to repeat the previous investigation for an FM victim who is restricted to using the FM channel closest to the TETRA band. This is illustrated in Figure 17.

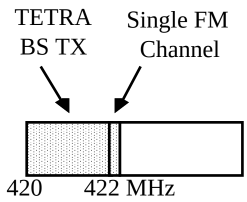

Figure 17 : The band allocations used to investigate the effect of increasing the minimum carrier separation when the victim has only a single channel

Table 16 provides the levels of interference for a range of minimum frequency separations. The TETRA base station density is fixed at 0.05 / km^2. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Minimum Frequency Separation	Active Interf. Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM BS	Probability of Interference for 12.5 kHz FM BS
25 kHz	0.05 / km^2	2.52 km	10.04 %	11.66 %
50 kHz	0.05 / km^2	2.52 km	9.52 %	11.11 %
100 kHz	0.05 / km^2	2.52 km	8.65 %	10.16 %
250 kHz	0.05 / km^2	2.52 km	7.71 %	9.13 %
500 kHz	0.05 / km^2	2.52 km	7.06 %	8.42 %

Table 16 : The probability of interference for an FM base station amongst a population of TETRA base stations for a range of minimum carrier separations when the victim has only a single channel

The level of interference decreases as the minimum frequency separation is increased.

4.1.4.3 The Effect of Increasing the Band Allocations

For this investigation the minimum frequency separation is maintained at its minimum and the band allocations increased. This is illustrated in Figure 18 for the case of 5 MHz band allocations.

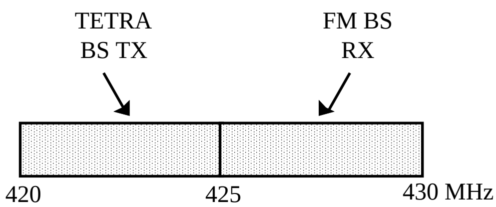

Figure 18 : One of the band allocations used to investigate the effect of increasing the band allocation size

Table 17 provides the levels of interference for a range of band allocation sizes. The TETRA base station density is fixed at 0.05 / km^2. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Band Allocation Size	Active Interf. Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM BS	Probability of Interference for 12.5 kHz FM BS
2 MHz	0.05 / km^2	2.52 km	7.31 %	8.69 %
3 MHz	0.05 / km^2	2.52 km	7.16 %	8.53 %
4 MHz	0.05 / km^2	2.52 km	7.10 %	8.47 %
5 MHz	0.05 / km^2	2.52 km	7.07 %	8.44 %

Table 17 : The probability of interference for an FM base station, amongst a population of TETRA base stations, for a range of band allocation sizes

The level of interference decreases slightly as the band allocation is increased.

4.2 The Effect of FM upon TETRA

Four interference scenarios can be identified :

- FM MS interfering with an TETRA MS
- FM MS interfering with an TETRA BS
- FM BS interfering with an TETRA MS
- FM BS interfering with an TETRA BS

Simulations have been completed for 25 kHz and 12.5 kHz FM systems. TETRA mobile stations are assumed to be 1 Watt. Only an urban area has been considered in this report.

4.2.1 FM MS Interfering with a TETRA MS

For this scenario it is possible for the interferer and victim to be very close to one another. However transmit powers and antenna gains are lower than those belonging to a base and the wanted signal strength will be greater than that received by a base - due to uplink and downlink power budgets. In all of the simulations in this section the victim TETRA system is assumed to have a 4 km cell radius providing a 90 % area availability.

4.2.1.1 The Effect of Active Interferer Density

The density of active interferers will be dependent upon the area being considered i.e. a sub-urban area is likely to have a lower density than an urban area. Correspondingly the level of interference in an urban area would be expected to be greater.

Figure 19 illustrates the band plan assumed for this investigation. 2 MHz of spectrum has been allocated to the downlink of TETRA and directly adjacent to this, 2 MHz has been allocated to FM.

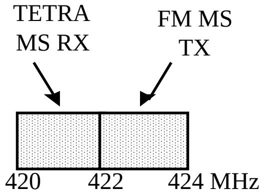

Figure 19 : The band allocations used to investigate the effect of increasing the active interferer density

Table 18 provides the levels of interference for a range of interferer densities. When TETRA mobiles were the interferers then the TETRA cell size was important because of the power control algorithm. FM mobiles do not use power control and so knowledge of the FM cell size is not required.

Active Interferer Density	Probability of Interference due to 25 kHz FM MS	Probability of Interference due to 12.5 kHz FM MS
0.5 / km^2	0.06 %	0.06 %
1 / km^2	0.12 %	0.12 %
2 / km^2	0.20 %	0.22 %
4 / km^2	0.45 %	0.46 %
5 / km^2	0.56 %	0.57 %
10 / km^2	1.10 %	1.12 %

Table 18 : The probability of interference for TETRA mobiles amongst a population of FM mobiles for a range of active interferer densities

The level of interference increases as the density of active interferers increases.

4.2.1.2 The Effect of Minimum Carrier Separation

For this investigation the same size bands as in the previous section are allocated but in this case the minimum frequency separation between the TETRA and FM bands is varied. This is illustrated in Figure 20.

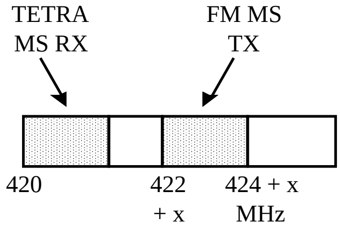

Figure 20 : The band allocations used to investigate the effect of increasing the minimum carrier separation

Table 19 provides the levels of interference for a range of minimum carrier separations. The FM active user density is fixed at 4 / km^2.

Minimum Carrier Separation	Probability of Interference due to 25 kHz FM MS	Probability of Interference due to 12.5 kHz FM MS
25 kHz	0.45 %	0.46 %
50 kHz	0.45 %	0.45 %
100 kHz	0.44 %	0.44 %
250 kHz	0.43 %	0.43 %
500 kHz	0.43 %	0.43 %

Table 19 : The Probability of Interference for TETRA mobiles amongst a population of FM mobiles for a range of minimum carrier separations

The level of interference remains virtually constant as the minimum carrier separation is increased.

The probabilities of interference calculated above are for a TETRA victim who is able to use any channel across the TETRA band. It is also of interest to repeat the previous investigation for a TETRA victim who is restricted to using the TETRA channel closest to the FM band. This is illustrated in Figure 21.

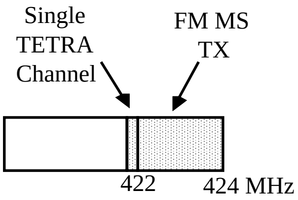

Figure 21 : The band allocations used to investigate the effect of increasing the minimum carrier separation when the victim has only a single channel

Table 20 provides the levels of interference for a range of minimum carrier separations. The FM active user density is fixed at 4 / km^2.

Minimum Carrier Separation	Probability of Interference due to 25 kHz FM MS	Probability of Interference due to 12.5 kHz FM MS
25 kHz	0.65 %	0.78 %
100 kHz	0.54 %	0.58 %
250 kHz	0.48 %	0.48 %
500 kHz	0.44 %	0.44 %
1 MHz	0.43 %	0.43 %

Table 20 : The probability of interference for TETRA mobiles amongst a population of FM mobiles for a range of minimum carrier separations when the victim has only a single channel

The levels of interference are slightly greater than for the case when the TETRA system had 2 MHz of channels allocated. This is due to the higher probability of smaller frequency offsets. There is a decrease in the level of interference as the minimum carrier separation is increased.

4.2.1.3 The Effect of Increasing the Band Allocations

For this investigation the minimum frequency separation is maintained at its minimum and the band allocations increased. This is illustrated in Figure 22 for the case of 5 MHz band allocations.

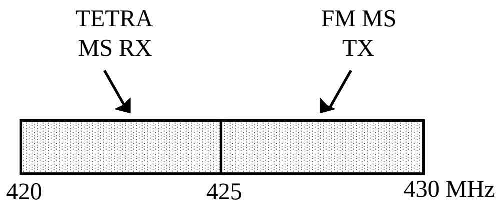

Figure 22 : One of the band allocations used to investigate the effect of increasing the band allocation size

Table 21 provides the levels of interference for a range of band allocation sizes. The FM active user density is fixed at 4 / km^2.

Band Allocation Size	Probability of Interference due to 25 kHz FM MS	Probability of Interference due to 12.5 kHz FM MS
2 MHz	0.45 %	0.46 %
3 MHz	0.44 %	0.44 %
4 MHz	0.43 %	0.43 %
5 MHz	0.43 %	0.43 %

Table 21 : The Probability of Interference for TETRA mobiles amongst a population of FM Mobiles for a range of band allocation sizes

The probability of interference does not change significantly as the band allocation is increased.

4.2.2 FM MS Interfering with an TETRA BS

This scenario involves a population of FM mobiles interfering with a victim TETRA base station. The interferer / victim link now includes the antenna gain of a base leading to increased levels of interference. The mean wanted signal strength arriving at the base will be less than that arriving at a mobile due to the uplink and downlink power budgets. In all of the simulations in this section the victim TETRA system is assumed to have a 4 km cell radius providing a 90 % area availability.

4.2.2.1 The Effect of Active Interferer Density

Figure 23 illustrates the band plan assumed for this investigation. 2 MHz of spectrum has been allocated to the uplink of TETRA and directly adjacent to this 2 MHz has been allocated to FM.

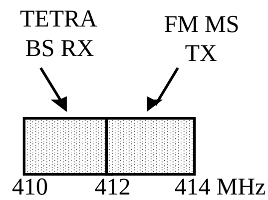

Figure 23 : The band allocations used to investigate the effect of increasing the active interferer density

Table 22 provides the levels of interference for a range of interferer densities.

Active Interferer Density	Probability of Interference due to 25 kHz FM MS	Probability of Interference due to 12.5 kHz FM MS
0.5 / km^2	0.62 %	0.63 %
1 / km^2	1.21 %	1.22 %
2 / km^2	2.32 %	2.34 %
4 / km^2	4.28 %	4.30 %
5 / km^2	5.20 %	5.22 %
10 / km^2	9.18 %	9.21 %

Table 22 : The probability of interference for a TETRA base station amongst a population of FM mobiles for a range of active interferer densities

The level of interference increases as the density of active interferers increases.

4.2.2.2 The Effect of Minimum Carrier Separation

Section 4.2.1.2 showed that the level of interference does not change significantly as the minimum carrier separation between the 2 MHz band allocations is increased. If however the TETRA victim is restricted to using the TETRA channel closest to the FM band then there is a reduction in the level of interference as the carrier separation is increased. This scenario is illustrated in Figure 24.

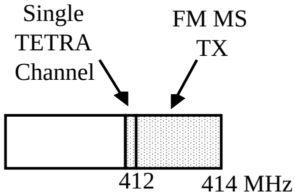

Figure 24 : The band allocations used to investigate the effect of increasing the minimum carrier separation when the victim has only a single channel

Table 23 provides the levels of interference for a range of minimum carrier separations. The FM active user density is fixed at 4 / km^2.

Minimum Carrier Separation	Probability of Interference due to 25 kHz FM BS	Probability of Interference due to 12.5 kHz FM BS
25 kHz	6.16 %	6.17 %
100 kHz	5.25 %	5.26 %
250 kHz	4.67 %	4.68 %
500 kHz	4.19 %	4.20 %
1 MHz	4.07 %	4.08 %

Table 23 : The probability of interference for a TETRA base station amongst a population of FM mobiles for a range of minimum carrier separations when the victim has only a single channel

Below 250 kHz minimum carrier separation, the levels of interference are slightly greater than for the case when the TETRA system had 2 MHz of channels allocated. This is due to the higher probability of smaller frequency offsets. There is a decrease in the level of interference as the minimum carrier separation is increased.

4.2.2.3 The Effect of Increasing the Band Allocations

Section 4.2.1.3 showed that the level of interference does not change significantly as the band allocations are increased beyond 2 MHz.

4.2.3 FM BS Interfering with an TETRA MS

For this scenario the density of interferers is relatively low. However, the transmit power is greater. The victim is receiving from a base station and will benefit from the downlink power budget. In all of the simulations in this section the victim TETRA system is assumed to have a 4 km cell radius which provides 90 % area availability.

4.2.3.1 The Effect of Active Interferer Density

Figure 25 illustrates the band plan assumed for this investigation. 2 MHz of spectrum has been allocated to the downlink of TETRA and directly adjacent to this, 2 MHz has been allocated to FM.

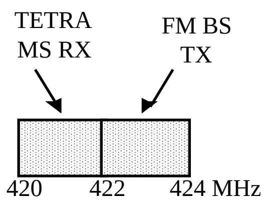

Figure 25 : The band allocations used to investigate the effect of increasing the active interferer density

Table 24 provides the levels of interference for a range of interferer densities. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Active Interferer Density	FM Cell Radius	Probability of Interference due to 25 kHz FM BS	Probability of Interference due to 12.5 kHz FM BS
0.01 / km^2	5.64 km	0.01 %	0.01 %
0.02 / km^2	3.99 km	0.02 %	0.02 %
0.05 / km^2	2.52 km	0.04 %	0.04 %
0.10 / km^2	1.78 km	0.08 %	0.08 %
0.20 / km^2	1.26 km	0.15 %	0.17 %

Table 24 : The probability of interference for TETRA mobiles amongst a population of FM base stations for a range of base station densities

The level of interference increases as the density of active interferers increases.

4.2.3.2 The Effect of Minimum Carrier Separation

Section 4.2.1.2 showed that the level of interference does not change significantly as the minimum carrier separation between the 2 MHz band allocations is increased. If however the TETRA victim is restricted to using the TETRA channel closest to the FM band then there is a reduction in the level of interference as the carrier separation is increased. This scenario is illustrated in Figure 26.

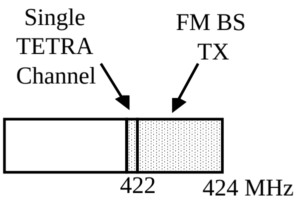

Figure 26 : The band allocations used to investigate the effect of increasing the minimum carrier separation when the victim has only a single channel

Table 25 provides the levels of interference for a range of minimum carrier separations. The FM active user density is fixed at 0.05 / km^2. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Minimum Carrier Separation	Active Interferer Density	FM Cell Radius	Probability of Interference due to 25 kHz FM BS	Probability of Interference due to 12.5 kHz FM BS
25 kHz	0.05 / km^2	2.52 km	0.08 %	0.15 %
100 kHz	0.05 / km^2	2.52 km	0.06 %	0.07 %
250 kHz	0.05 / km^2	2.52 km	0.05 %	0.05 %
500 kHz	0.05 / km^2	2.52 km	0.04 %	0.04 %
1 MHz	0.05 / km^2	2.52 km	0.04 %	0.04 %

Table 25 : The probability of interference for TETRA mobiles amongst a population of FM base stations for a range of minimum carrier separations when the victim has only a single channel

The levels of interference are slightly greater than for the case when the TETRA system had 2 MHz of channels allocated. This is due to the higher probability of smaller frequency offsets. There is a decrease in the level of interference as the minimum carrier separation is increased.

4.2.3.3 The Effect of Increasing the Band Allocations

Section 4.2.1.3 showed that the level of interference does not change significantly as the band allocations are increased beyond 2 MHz.

4.2.4 FM BS Interfering with an TETRA BS

For this scenario the density of interferers is relatively low. However, the transmit power is greater. In addition the interferer to victim path includes two high gain antennas and the victim is receiving from a mobile. In all of the simulations in this section the victim TETRA system is assumed to have a 4 km cell radius which provides 90 % area availability.

4.2.4.1 The Effect of Active Interferer Density

Figure 27 illustrates the band plan assumed for this investigation. 2 MHz of spectrum has been allocated to the uplink of TETRA and directly adjacent to this 2 MHz has been allocated to FM.

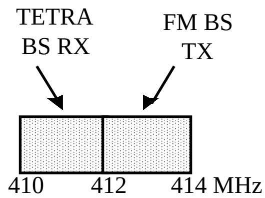

Figure 27 : The band allocations used to investigate the effect of increasing the active interferer density

Table 26 provides the levels of interference for a range of interferer densities. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Active Interferer Density	FM Cell Radius	Probability of Interference due to 25 kHz FM BS	Probability of Interference due to 12.5 kHz FM BS
0.01 / km^2	5.64 km	0.50 %	0.63 %
0.02 /km^2	3.99 km	1.01 %	1.21 %
0.05 / km^2	2.52 km	2.41 %	2.79 %
0.10 / km^2	1.78 km	4.58 %	5.14 %
0.20 / km^2	1.26 km	8.12 %	8.98 %

Table 26 : The Probability of Interference for a TETRA base station amongst a population of FM base stations for a range of active FM base station densities

The level of interference increases as the density of active interferers increases. It should be noted that the higher densities of FM base stations represent hot spots. A typical urban FM cell has a radius of approximately 7.8 km corresponding to a density of 0.01 km^2. Using additional filtering in the transmitting or receiving base can reduce the levels of interference in hot spots. Cavity resonators can be used in the transmitting base to reduce levels of unwanted emissions. A typical cavity resonator in the 400 MHz band can provide an attenuation of 10 dB at a frequency offset of 400 kHz. The effect of such a cavity resonator upon the levels of interference for a 25 kHz FM base station is shown in Table 27. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Active Interferer Density	FM Cell Radius	Prob. of Interf. due to 25 kHz FM BS without a Cavity Resonator	Prob. of Interf. due to 25 kHz FM BS with a Cavity
0.01 / km^2	5.64 km	0.50 %	0.45 %
0.02 / km^2	3.99 km	1.01 %	0.90 %
0.05 / km^2	2.52 km	2.41 %	2.14 %
0.10 / km^2	1.78 km	4.58 %	4.05 %
0.20 / km^2	1.26 km	8.12 %	7.32 %

Table 27 : The probability of interference for a TETRA base station, amongst a population of FM base stations, for a range of active interferer densities

The levels of interference are reduced (somewhat), by the additional filtering in the transmitting base station but not significantly. This indicates that receiver blocking is having a significant effect and additional filtering in the receiving base station would be required to reduce levels of interference significantly.

4.2.4.2 The Effect of Minimum Carrier Separation

Section 4.2.1.2 showed that the level of interference does not change significantly as the minimum carrier separation between the 2 MHz band allocations is increased. If however the TETRA victim is restricted to using the TETRA channel closest to the FM band then there is a reduction in the level of interference as the carrier separation is increased. This scenario is illustrated in Figure 28.

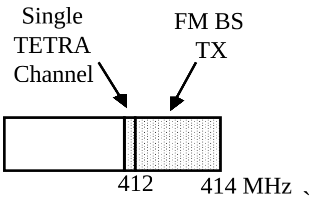

Figure 28 : The band allocations used to investigate the effect of increasing the minimum carrier separation when the victim has only a single channel

Table 28 provides the levels of interference for a range of minimum frequency separations. The FM active user density is fixed at 0.05 / km^2. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Minimum Frequency Separation	Active Interferer Density	FM Cell Radius	Probability of Interference due to 25 kHz FM BS	Probability of Interference due to 12.5 kHz FM BS
25 kHz	0.05 / km^2	2.52 km	7.22 %	7.25 %
100 kHz	0.05 / km^2	2.52 km	4.97 %	4.99 %
250 kHz	0.05 / km^2	2.52 km	3.15 %	3.16 %
500 kHz	0.05 / km^2	2.52 km	2.62 %	2.63 %
1 MHz	0.05 / km^2	2.52 km	2.41 %	2.42 %

Table 28 : The probability of interference for a TETRA base station amongst a population of FM base stations for a range of minimum carrier separations when the victim has only a single channel

The levels of interference are slightly greater than for the case when the TETRA system had 2 MHz of channels allocated. This is due to the higher probability of smaller frequency offsets. There is a decrease in the level of interference as the minimum carrier separation is increased.

4.2.4.3 The Effect of Increasing the Band Allocations

Section 4.2.1.3 showed that the level of interference does not change significantly as the band allocations are increased beyond 2 MHz.

5 CO-SITED SYSTEMS

Systems, which are co-sited, use the same mast for their base station antennas. This is difficult to achieve over an entire system as both systems would require identical cell sizes. However it is likely to occur at some base stations where there are not many suitable antenna sites. An illustration of a co-sited cell is provided in Figure 29.

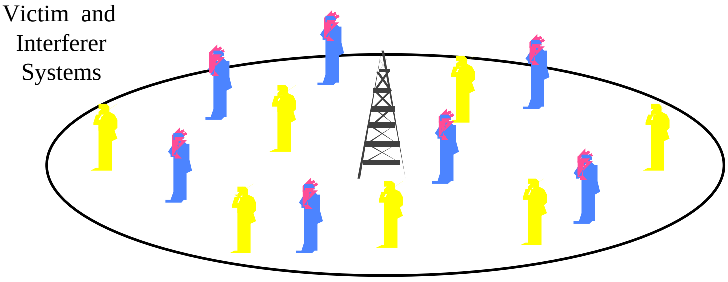

Figure 29 : A pair of co-sited cell

The hypothesis concerning propagation model, power control, cell sizes and number of transmitters and receivers per base station are the same as in Chapter 4.

Simulations have been completed to investigate the effect of active user density, minimum frequency separation, band allocation size and power control. The effect of TETRA upon FM will be investigated first followed by the effect of FM upon TETRA.

5.1 The Effect of TETRA upon FM

Four interference scenarios can be identified :

- TETRA MS interfering with an FM MS
- TETRA MS interfering with an FM BS
- TETRA BS interfering with an FM MS
- TETRA BS interfering with an FM BS

It is assumed that the FM system is either 25 kHz, 20 kHz or 12.5 kHz. Parameters for each system are specified in Appendix B. Simulations have been completed for 25 kHz and 12.5 kHz systems. The only difference between the parameters for a 25 kHz system and a 20 kHz system is the receiver bandwidth. For a 25 kHz system the receiver bandwidth is 15 kHz whereas for a 20 kHz system it is 12 kHz. This means that levels of interference for a 20 kHz system will be slightly lower than for 25 kHz. Providing levels are acceptable for 25 kHz they will also be acceptable for 20 kHz. TETRA mobiles are assumed to be 1 Watt. Only an urban area has been considered in this report.

5.1.1 TETRA MS interfering with an FM MS

For this scenario it is possible for the interferer and victim to be very close. However transmit powers and antenna gains are lower than those belonging to a base and the wanted signal strength will be greater than that received by a base - due to uplink and downlink power budgets. In all of the simulations in this section the victim FM system is assumed to have a 7.8 km cell radius which provides a 90 % availability.

5.1.1.1 The Effect of Active Interferer Density

The density of active interferers will be dependent upon the area being considered i.e. a sub-urban area is likely to have a lower density than an urban area. Correspondingly the level of interference in an urban area would be expected to be greater.

Figure 30 illustrates the band plan assumed for this investigation. 2 MHz of spectrum has been allocated to the uplink of TETRA and directly adjacent to this, 2 MHz has been allocated to FM.

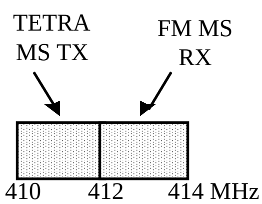

Figure 30 : The band allocations used to investigate the effect of increasing the active interferer density

Table 29 provides the levels of interference for a range of interferer densities and cell sizes. The cell sizes are based upon the density and carriers per cell assumed and are representative of those used in practice.

Active Interferer Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM MS	Probability of Interference for 12.5 kHz FM MS
0.5 / km^2	4.79 km	0.04 %	0.04 %
1 / km^2	3.39 km	0.09 %	0.09 %
1 / km^2	3.91 km	0.09 %	0.09 %
2 / km^2	2.39 km	0.19 %	0.19 %
2 / km^2	2.75 km	0.19 %	0.19 %
4 / km^2	1.95 km	0.36 %	0.37 %
5 / km^2	1.75 km	0.44 %	0.47 %
10 / km^2	1.24 km	0.84 %	0.88 %

Table 29 : The probability of interference for an FM mobile amongst a population of TETRA mobiles for a range of active interferer densities

The level of interference increases as the density of active interferers increases. The levels of interference are greater than those for a non-cosited pair of TETRA and FM systems. This is because when the victim is far from its wanted signal transmitter i.e. is at the cell edge, then the closest interferer is also far from its intended receiver - the wanted signal transmitter and the interferon's intended receiver are co-located base stations. This means that when the victim has a relatively low wanted signal strength then the nearest interferer is almost always transmitting at a high power level i.e. the near far effect. When the base stations are not co-sited this scenario does not occur so frequently and so the probability of interference is lower.

5.1.1.2 The Effect of Minimum Carrier Separation

For this investigation the same size bands as in the previous section are allocated but in this case the minimum carrier separation between the TETRA and FM bands is varied. This is illustrated in Figure 31.

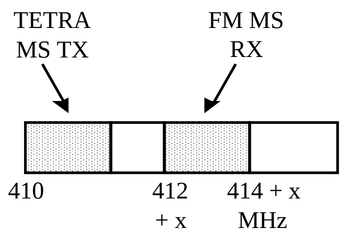

Figure 31 : The band allocations used to investigate the effect of increasing the minimum frequency separation

Table 30 provides the levels of interference for a range of minimum carrier separations. The TETRA active user density is fixed at 4 / km^2 and the TETRA cell size at 1.95 km.

Minimum Carrier Separation	Active Interf. Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM MS	Probability of Interference for 12.5 kHz FM MS
25 kHz	4 / km^2	1.95 km	0.36 %	0.37 %
50 kHz	4 / km^2	1.95 km	0.36 %	0.37 %
100 kHz	4 / km^2	1.95 km	0.36 %	0.37 %
250 kHz	4 / km^2	1.95 km	0.36 %	0.37 %
500 kHz	4 / km^2	1.95 km	0.36 %	0.37 %

Table 30 : The probability of interference for an FM mobile amongst a population of TETRA mobiles for a range of minimum carrier separations

The probabilities of interference remain constant as the minimum carrier separation is increased. This is because the TETRA out-of-band emissions characteristic is flat for frequency offsets above 250 kHz. The absolute levels of interference are greater than for the non-cosited case for the same reason described in section 5.1.1.1.

The probabilities of interference calculated above are for an FM mobile victim who is able to use any channel across the FM band. It is also of interest to repeat the previous investigation for an FM victim who is restricted to using the FM channel closest to the TETRA band. This is illustrated in Figure 32.

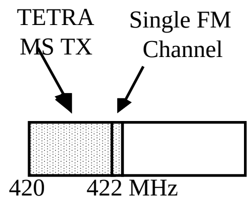

Figure 32 : The band allocations used to investigate the effect of increasing the minimum carrier separation when the victim has only a single channel

Table 31 provides the levels of interference for a range of minimum carrier separations. The TETRA active user density is fixed at 4 / km^2 and the TETRA cell size at 1.95 km.

Minimum Carrier Separation	Active Interf. Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM MS	Probability of Interference for 12.5 kHz FM MS
25 kHz	4 / km^2	1.95 km	0.38 %	0.40 %
50 kHz	4 / km^2	1.95 km	0.37 %	0.38 %
100 kHz	4 / km^2	1.95 km	0.37 %	0.38 %
250 kHz	4 / km^2	1.95 km	0.36 %	0.37 %
500 kHz	4 / km^2	1.95 km	0.36 %	0.37 %

Table 31 : The probability of interference for an FM mobile amongst a population of TETRA mobiles for a range of minimum carrier separations when the victim has only a single channel

The levels of interference are slightly greater than for the case when the FM system had 2 MHz of channels allocated. This is due to the higher probability of smaller frequency offsets. There is a small decrease in the level of interference as the minimum carrier separation is increased.

5.1.1.3 The Effect of Increasing the Band Allocations

For this investigation the minimum carrier separation is maintained at its minimum and the band allocations increased. This is illustrated in Figure 33 for the case of 5 MHz band allocations.

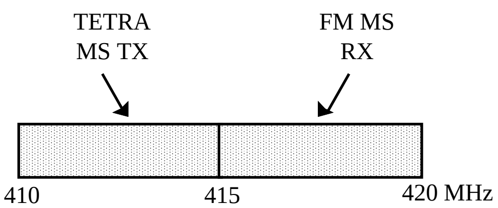

Figure 33 : One of the band allocations used to investigate the effect of increasing the band allocation size

Table 32 provides the levels of interference for a range of band allocation sizes. The TETRA active user density is fixed at 4 / km^2 and the TETRA cell size at 1.95 km.

Band Allocation Size	Active Interf. Density	TETR A Cell Radius	Probability of Interference for 25 kHz FM MS	Probability of Interference for 12.5 kHz FM MS
2 MHz	4 / km^2	1.95 km	0.36 %	0.37 %
3 MHz	4 / km^2	1.95 km	0.36 %	0.37 %
4 MHz	4 / km^2	1.95 km	0.36 %	0.37 %
5 MHz	4 / km^2	1.95 km	0.36 %	0.37 %

Table 32 : The probability of interference for an FM mobile amongst a population of TETRA mobiles for a range of band allocation sizes

The probability of interference does not change as the band allocation is increased. This is due to the TETRA mobile station out-of-band emissions characteristic being flat above 250 kHz. The absolute levels of interference are greater than for the non-cosited case for the same reason described in section 5.1.1.1.

5.1.1.4 The Effect of not using Power Control

When power control is not used then the levels of interference for this scenario are identical to those for the non-cosited scenario shown in Table 5. They are identical because the results do not rely upon the TETRA mobile station to TETRA base station distance but only upon the TETRA mobile station to FM mobile station and FM mobile station to FM base station distances.

5.1.2 TETRA MS Interfering with an FM BS

This scenario involves a population of mobiles interfering with a victim base. The interferer to victim link now includes the antenna gain of a base leading to increased levels of interference. In addition the wanted signal strength arriving at the base will be less than that arriving at a mobile due to the uplink and downlink power budgets. In all of the simulations in this section the victim FM system is assumed to have a 7.8 km cell radius which provides a 90 % availability.

Due to the TETRA and FM systems being co-sited the distance from the interferer to the victim is equal to the distance between the interferer and its intended receiver. This has implications upon the effect of power control. Whenever the interferer is close to the victim then it will also be close to its intended receiver and so will be transmitting at a relatively low power. Thus for this scenario levels of interference will be lower than for the corresponding non-cosited case.

5.1.2.1 The Effect of Active Interferer Density

Figure 34 illustrates the band plan assumed for this investigation. 2 MHz of spectrum has been allocated to the uplink of TETRA and directly adjacent to this, 2 MHz has been allocated to FM.

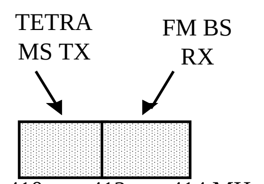

Figure 34 : The band allocations used to investigate the effect of increasing the active interferer density

Table 33 provides the levels of interference for a range of interferer densities and cell sizes. The cell sizes are based upon the density and carriers per cell assumed and are representative of those used in practice.

Active Interferer Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM BS	Probability of Interference for 12.5 kHz FM BS
0.5 / km^2	4.79 km	0.11 %	0.13 %
1 / km^2	3.39 km	0.21 %	0.26 %
1 / km^2	3.91 km	0.21 %	0.26 %
2 / km^2	2.39 km	0.43 %	0.52 %
2 / km^2	2.75 km	0.43 %	0.52 %
4 / km^2	1.95 km	0.78 %	0.98 %
5 / km^2	1.75 km	0.98 %	1.22 %
10 / km^2	1.24 km	1.76 %	2.17 %

Table 33 : The probability of interference for an FM base station amongst a population of TETRA mobiles for a range of active interferer densities

The level of interference increases as the density of active interferers increases. The levels of interference are lower than those for the non-cosited case because when an interfering TETRA mobile station is close to the victim FM base station then it is also close to its intended receiving base station and is able to transmit at a relatively low power level. Interfering mobiles that are transmitting at a high power are further away from the victim and so have a greater path loss.

5.1.2.2 The Effect of Minimum Carrier Separation

Section 5.1.1.2 showed that the level of interference does not change as the minimum carrier separation between the 2 MHz band allocations is increased. If however the FM victim is restricted to using the FM channel closest to the TETRA band then there is a reduction in the level of interference as the carrier separation is increased. This scenario is illustrated in Figure 35.

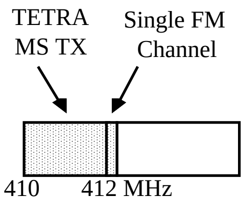

Figure 35 : The band allocations used to investigate the effect of increasing the minimum carrier separation when the victim has only a single channel

Table 34 provides the levels of interference for a range of minimum carrier separations. The TETRA active user density is fixed at 4 / km^2 and the TETRA cell size at 1.95 km.

Minimum Carrier Separation	Active Interf. Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM BS	Probability of Interference for 12.5 kHz FM BS
25 kHz	4 / km^2	1.95 km	0.91 %	1.12 %
50 kHz	4 / km^2	1.95 km	0.89 %	1.08 %
100 kHz	4 / km^2	1.95 km	0.85 %	1.04 %
250 kHz	4 / km^2	1.95 km	0.78 %	0.97 %
500 kHz	4 / km^2	1.95 km	0.78 %	0.97 %

Table 34 : The probability of interference for an FM base station amongst a population of TETRA mobiles for a range of minimum carrier separations when the victim has only a single channel

The levels of interference are slightly greater than for the case when the FM system had 2 MHz of channels allocated. This is due to the higher probability of smaller frequency offsets. There is a decrease in the level of interference as the minimum carrier separation is increased. The absolute levels of interference are less than for the non-cosited case for the same reason described in section 5.1.2.1.

5.1.2.3 The Effect of Increasing the Band Allocations

Section 5.1.1.3 showed that the level of interference does not change as the allocated bands are increased from 2 MHz to 5 MHz.

5.1.2.4 The Effect of not using Power Control

When power control is not used then the levels of interference for this scenario are identical to those for the non-cosited scenario shown in Table 8. They are identical because the results do not rely upon the TETRA mobile station to TETRA base station distance but only upon the TETRA mobile station to FM base station and FM base station to FM mobile station distances.

5.1.3 TETRA BS interfering with an FM MS

For this scenario the density of interferers is relatively low. However, the transmit power is greater and no power control is used. The victim is receiving from a base station and will benefit from the downlink power budget. In all of the simulations in this section the victim FM system is assumed to have a 7.8 km cell radius which provides 90 % availability.

Due to the TETRA and FM systems being co-sited the distance from the interferer to the victim is equal to the distance between the victim and its wanted signal transmitter. Whenever the victim is close to an interferer then it will also be close to its wanted signal transmitter and so will have a relatively good signal strength margin. Thus for this scenario levels of interference will be lower than for the corresponding non-cosited case.

5.1.3.1 The Effect of Active Interferer Density

Figure 36 illustrates the band plan assumed for this investigation. 2 MHz of spectrum has been allocated to the downlink of TETRA and directly adjacent to this, 2 MHz has been allocated to FM.

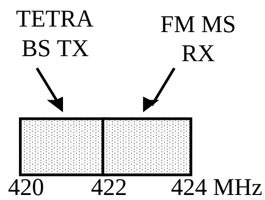

Figure 36 : The band allocations used to investigate the effect of increasing the active interferer density

Table 35 provides the levels of interference for a range of interferer densities. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Active Interferer Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM MS	Probability of Interference for 12.5 kHz FM MS
0.01 / km^2	5.64 km	0.00 %	0.00 %
0.02 / km^2	3.99 km	0.00 %	0.00 %
0.05 / km^2	2.52 km	0.00 %	0.00 %
0.10 / km^2	1.78 km	0.00 %	0.00 %
0.20 / km^2	1.26 km	0.00 %	0.00 %

Table 35 : The probability of interference for an FM mobile amongst a population of TETRA base stations for a range of active interferer densities

The levels of interference are below 0.01 % for all interferer densities considered. This is due to the victim always having a high wanted signal strength when it is close to an interferer.

5.1.3.2 The Effect of Minimum Carrier Separation

For this investigation the same size bands as in the previous section are allocated but in this case the minimum carrier separation between the TETRA and FM bands is varied. This is illustrated in Figure 37.

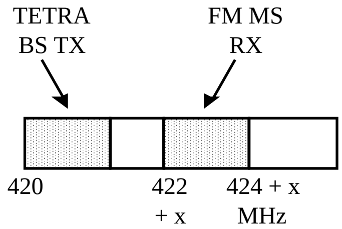

Figure 37 : The band allocations used to investigate the effect of increasing the minimum carrier separation

Table 36 provides the levels of interference for a range of minimum carrier separations. The TETRA base station density is fixed at 0.05 / km^2. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Minimum Carrier Separation	Active Interf. Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM MS	Probability of Interference for 12.5 kHz FM MS
25 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
50 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
100 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
250 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
500 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %

Table 36 : The probability of interference for an FM mobile amongst a population of TETRA base stations for a range of minimum carrier separations

The probabilities of interference remain below 0.01 % as the minimum carrier separation is increased. These probabilities are for an FM victim who is able to use any channel across the FM band. It is also of interest to repeat the investigation for an FM victim who is restricted to using the FM channel closest to the TETRA band. This is illustrated in Figure 38.

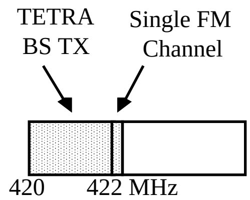

Figure 38 : The band allocations used to investigate the effect of increasing the minimum carrier separation when the victim has only a single channel

Table 37 provides the levels of interference for a range of minimum carrier separations. The TETRA base station density is fixed at 0.05 / km^2. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Minimum Carrier Separation	Active Interf. Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM MS	Probability of Interference for 12.5 kHz FM MS
25 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
50 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
100 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
250 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
500 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %

Table 37 : The probability of interference for an FM Mobile amongst a population of TETRA base stations for a range of minimum carrier separations when the victim has only a single channel

The levels of interference remain below 0.01 % for the reason described in section 5.1.3.1.

5.1.3.3 The Effect of Increasing the Band Allocations

For this investigation the minimum carrier separation is maintained at its minimum and the band allocations increased. This is illustrated in Figure 39 for the case of 5 MHz band allocations.

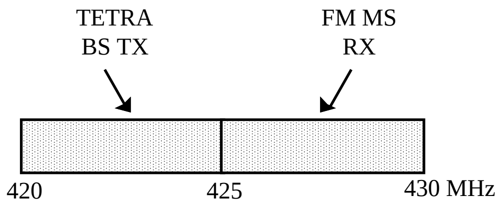

Figure 39 : One of the band allocations used to investigate the effect of increasing the band allocation size

Table 38 provides the levels of interference for a range of band allocation sizes. The TETRA base station density is fixed at 0.05 / km^2. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Band Allocation Size	Active Interf. Density	TETRA Cell Radius	Probability of Interference for 25 kHz FM MS	Probability of Interference for 12.5 kHz FM MS
2 MHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
3 MHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
4 MHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
5 MHz	0.05 / km^2	2.52 km	0.00 %	0.00 %

Table 38 : The probability of interference for FM mobiles amongst a population of TETRA base stations for a range of band allocation sizes

The levels of interference remain below 0.01 % for the reason described in section 5.1.3.1.

5.1.4 TETRA BS Interfering with an FM BS

Calculations have not been carried out for this scenario as control of the interference depends upon careful site engineering to provide adequate isolation between antennas sharing the same mast. The antennas will have to be placed carefully such that significant power is not coupled from one to the other. Additional filtering in one system may be required to protect the other. Frequency coordination between system operators would greatly ease any difficulties encountered.

5.2 The Effect of FM upon TETRA

Four interference scenarios can be identified :

- FM MS interfering with an TETRA MS
- FM MS interfering with an TETRA BS
- FM BS interfering with an TETRA MS
- FM BS interfering with an TETRA BS

Simulations have been completed for 25 kHz and 12.5 kHz FM systems. TETRA mobile stations are assumed to be 1 Watt. Only an urban area has been considered in this report.

5.2.1 FM MS Interfering with an TETRA MS

Due to FM mobile stations not using power control, the levels of interference for this scenario are identical to those for the non-cosited scenarios presented in Section 4.2.1. They are identical because the results do not rely upon the FM mobile station to FM base station distance but only upon the FM mobile station to TETRA mobile station and TETRA mobile station to TETRA base station distances.

5.2.2 FM MS Interfering with an TETRA BS

Due to FM mobile stations not using power control, the levels of interference for this scenario are identical to those for the non-cosited scenarios presented in Section 4.2.2. They are identical because the results do not rely upon the FM mobile station to FM base station distance but only upon the FM mobile station to TETRA base station and TETRA base station to TETRA mobile station distances.

5.2.3 FM BS Interfering with an TETRA MS

For this scenario the density of interferers is relatively low. However, the transmit power is greater. The victim is receiving from a base station and will benefit from the downlink power budget. In all of the simulations in this section the victim TETRA system is assumed to have a 4 km cell radius which provides 90 % area availability.

Due to the TETRA and FM systems being co-sited the distance from the interferer to the victim is equal to the distance between the victim and its wanted signal transmitter. Whenever the victim is close to an interferer then it will also be close to its wanted signal transmitter and so will have a relatively good signal strength margin. Thus for this scenario levels of interference will be lower than for the corresponding non-cosited case.

5.2.3.1 The Effect of Active Interferer Density

Figure 40 illustrates the band plan assumed for this investigation. 2 MHz of spectrum has been allocated to the uplink of TETRA and directly adjacent to this, 2 MHz has been allocated to FM.

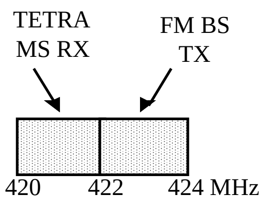

Figure 40 : The band allocations used to investigate the effect of increasing the active interferer density

Table 39 provides the levels of interference for a range of interferer densities. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Active Interferer Density	FM Cell Radius	Probability of Interference due to 25 kHz FM BS	Probability of Interference due to 12.5 kHz FM BS
0.01 / km^2	5.64 km	0.00 %	0.00 %
0.02 / km^2	3.99 km	0.00 %	0.00 %
0.05 / km^2	2.52 km	0.00 %	0.00 %
0.10 / km^2	1.78 km	0.00 %	0.00 %
0.20 / km^2	1.26 km	0.00 %	0.00 %

Table 39 : The probability of interference for TETRA mobiles amongst a population of FM base stations for a range of base station densities

The levels of interference are below 0.01 % for all interferer densities considered. This is due to the victim always having a high wanted signal strength when it is close to an interferer.

5.2.3.2 The Effect of Minimum Carrier Separation

For this investigation the same size bands as in the previous section are allocated but in this case the minimum carrier separation between the TETRA and FM bands is varied. This is illustrated in Figure 41.

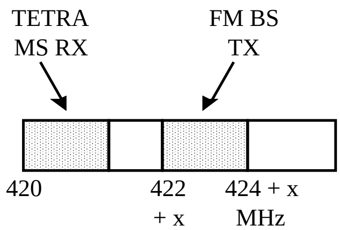

Figure 41 : The band allocations used to investigate the effect of increasing the minimum carrier separation

Table 40 provides the levels of interference for a range of minimum carrier separations. The FM base station density is fixed at 0.05 / km^2. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Minimum Carrier Separation	Active Interf. Density	FM Cell Radius	Probability of Interference due to 25 kHz FM BS	Probability of Interference due to 12.5 kHz FM BS
25 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
50 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
100 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
250 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
500 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %

Table 40 : The probability of interference for an TETRA mobile amongst a population of FM base stations for a range of minimum carrier separations

The probabilities of interference remain below 0.01 % as the minimum carrier separation is increased. These probabilities are for a TETRA victim who is able to use any channel across the TETRA band. It is also of interest to repeat the investigation for an TETRA victim who is restricted to using the TETRA channel closest to the FM band. This is illustrated in Figure 42.

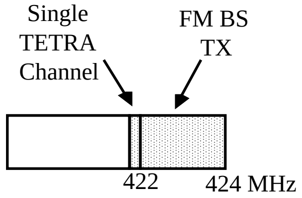

Figure 42 : The Band Allocations used to Investigate the Effect of Increasing the Minimum carrier Separation when the Victim has only a Single Channel

Table 41 provides the levels of interference for a range of minimum frequency separations. The FM base station density is fixed at 0.05 / km^2. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Minimum Frequency Separation	Active Interf. Density	FM Cell Radius	Probability of Interference due to 25 kHz FM BS	Probability of Interference due to 12.5 kHz FM BS
25 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
100 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
250 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
500 kHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
1 MHz	0.05 / km^2	2.52 km	0.00 %	0.00 %

Table 41 : The probability of interference for TETRA mobiles amongst a population of FM base stations for a range of minimum carrier separations when the victim has only a single channel

The levels of interference remain below 0.01 % for the reason described in section 5.2.3.1.

5.2.3.3 The Effect of Increasing the Band Allocations

For this investigation the minimum carrier separation is maintained at its minimum and the band allocations increased. This is illustrated in Figure 43 for the case of 5 MHz band allocations.

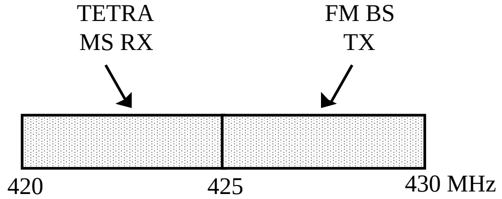

Figure 43 : One of the band allocations used to investigate the effect of increasing the band allocation size

Table 42 provides the levels of interference for a range of band allocation sizes. The TETRA base station density is fixed at 0.05 / km^2. The cell radius figures shown are derived directly from the interferer densities but are not directly used in the simulation.

Band Allocation Size	Active Interf. Density	FM Cell Radius	Probability of Interference due to 25 kHz FM BS	Probability of Interference due to 12.5 kHz FM BS
2 MHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
3 MHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
4 MHz	0.05 / km^2	2.52 km	0.00 %	0.00 %
5 MHz	0.05 / km^2	2.52 km	0.00 %	0.00 %

Table 42 : The probability of interference for TETRA mobiles amongst a population of FM base stations for a range of band allocation sizes

The levels of interference remain below 0.01 % for the reason described in section 5.2.3.1.

5.2.4 FM BS Interfering with an TETRA BS

Calculations have not been carried out for this scenario as control of the interference depends upon careful site engineering to provide adequate isolation between antennas sharing the same mast. The antennas will have to be placed carefully such that significant power is not coupled from one to the other. Additional filtering in one system may be required to protect the other. Frequency coordination between system operators would greatly ease any difficulties encountered.

6 TETRA DIRECT MODE

One type of TETRA direct mode operation involves mobile to mobile communication without the use of any system infrastructure. It is simplex and uses a 4 slot TDMA structure similar to that used for trunked mode. Direct mode is particularly useful in providing communication capability, outside normal coverage and in high user densities e.g. at the scene of an accident involving all three emergency services. The second of these applications shall be studied. The first will normally be used in areas where there are not high densities of other users who are likely to suffer from or cause interference.

Working Group 2 of ETSI technical committee RES 6 (EPT) has studied intra-system interference levels due to TETRA direct mode [2]. To achieve this they defined three interference scenarios - minor, moderate and major accidents. The details of these scenarios are specified below in Tables 43, 44 and 45.

DMO Scenario 1: Minor Accident

Area of accident - 0.126 km^2 (200m radius circle)

2 Police Vehicles	3 Policemen/vehicle	6 Policemen
1 Fire Engine	6 Firemen/vehicle	6 Firemen
2 Ambulances	2 Medics/vehicle	4 Medics

	1 Watt	3 Watt	10 Watt
Police	6	2	0
Fire Service	3	1	0
Ambulance Service	2	2	0
Total	**11**	**5**	**0**

Table 43 : The number of TETRA radios assumed for DMO scenario 1

DMO Scenario 2: Moderate Accident

Area of accident - 0.196 km^2 (250m radius circle)

5 Police Vehicles	4 Policemen/vehicle	20 Policemen
4 Fire Engines	6 Firemen/vehicle	24 Firemen
4 Ambulances	2 Medics/vehicle	8 Medics

	1 Watt	3 Watt	10 Watt
Police	20	5	1
Fire Service	12	4	0
Ambulance Service	4	4	0
Total	**36**	**13**	**1**

Table 44 : The number of TETRA radios assumed for DMO scenario 2

[2] ETSI STC RES6.2(95)142 ‘DMO Interference Scenarios’ (ETSI PT TETRA WG2)

DMO Scenario 3: Major Accident

Area of accident - 0.283 km^2 (300m radius circle)

10 Police Vehicles	4 Policemen/vehicle	40 Policemen
8 Fire Engines	6 Firemen/vehicle	48 Firemen
8 Ambulances	2 Medics/vehicle	16 Medics

	1 Watt	3 Watt	10 Watt
Police	40	10	1
Fire Service	24	8	1
Ambulance Service	8	8	1
Total	**72**	**26**	**3**

Table 45 : The number of TETRA radios assumed for DMO scenario 3

It is assumed that each policeman has a 1 Watt portable and that each police vehicle has a 3 Watt mobile. For the fire and ambulance services a 1 Watt portable is shared between 2 users and each vehicle has a 3 Watt mobile. 10 Watt repeaters are assumed when the number of users is high. It is further assumed that 10 % of the users are active at any one point in time. TETRA direct mode does not include a power control algorithm and so all radios transmit at full power.

Two interference scenarios can be identified :

- TETRA DMO MS interfering with an FM MS
- TETRA DMO MS interfering with an FM BS.

It is assumed that the FM system is either 25 kHz, 20 kHz or 12.5 kHz. Parameters for each system are specified in Appendix B. Simulations have been completed for 25 kHz and 12.5 kHz systems. The only difference between the parameters for a 25 kHz system and a 20 kHz system is the receiver bandwidth. For a 25 kHz system the receiver bandwidth is 15 kHz whereas for a 20 kHz system it is 12 kHz. This means that levels of interference for a 20 kHz system will be slightly lower than for 25 kHz. Providing levels are acceptable for 25 kHz they will also be acceptable for 20 kHz.

6.1 TETRA DMO MS Interfering with an FM MS

This interference scenario can be further sub-divided into the cases for when the victim FM mobile station is constrained to being within the direct mode call area and for when it is either inside or outside the direct mode call area. The former may apply if for example the police and fire services upgrade to a TETRA system but the ambulance service continues to use FM. In this case there will be FM users within the area of the direct mode call. The victim FM system is assumed to have a 7.8 km cell radius, which provides a 90 % area availability.

6.1.1 FM MS is within the area of the DMO call

Figure 44 illustrates the scenario for when the victim FM receiver is constrained to remain within the area of the direct mode call. The position of the direct mode call area is randomly placed within the FM cell for each simulation trial.

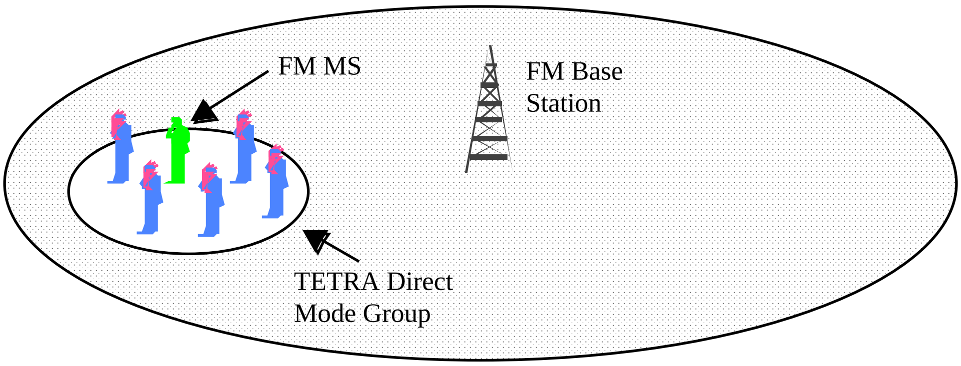

Figure 44 : The Direct Mode interference scenario when the victim FM MS is within the area of the Direct Mode call

It has been assumed that the TETRA system has a total of 2 MHz in the TETRA uplink band. The FM system is assumed to have 2 MHz of channels directly adjacent to the TETRA band. This is shown in Figure 45.

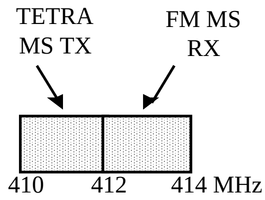

Figure 45 : The Direct Mode interference scenario when the victim FM MS is within the area of the Direct Mode call

Simulations have been completed for all three direct mode scenarios. The results are presented in Table 46.

Direct Mode Scenario	Probability of Interference to a 25 kHz FM MS	Probability of Interference to a 12.5 kHz FM MS
1	1.13 %	1.18 %
2	2.27 %	2.34 %
3	3.09 %	3.24 %

Table 46 : The probability of interference for an FM mobile within the area of a TETRA Direct Mode group

The probability of interference increases as the direct mode scenario involves more users. It is interesting to compare these results with those in Table 5 - TETRA mobiles interfering with an FM mobile for the case of no power control. The effective active user density for direct mode scenario 1 is 13 / km^2. The maximum density considered in Table 5 is 10 / km^2 and generates a probability of interference of 0.86 % for a 25 kHz FM mobile station. This agrees with the 1.13 % produced by the direct mode scenario with a greater active user density.

6.1.2 FM MS is inside or outside the area of the DMO call

Figure 46 illustrates the scenario for when the victim FM receiver outside the area of the direct mode call. The position of the direct mode call area is randomly placed within the FM cell for each simulation trial.

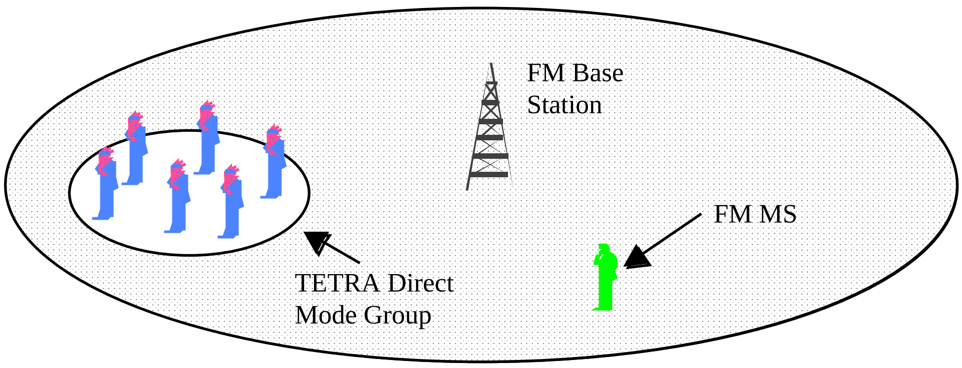

Figure 46 : The Direct Mode interference scenario when the victim FM MS is outside the area of the Direct Mode call

The same channels are assumed as for the previous investigation - shown in Figure 45. Simulations have been completed for all three direct mode scenarios. Table 47 presents the results.

Direct Mode Scenario	Probability of Interference to a 25 kHz FM MS	Probability of Interference to a 12.5 kHz FM MS
1	0.00 %	0.00 %
2	0.00 %	0.00 %
3	0.01 %	0.01 %

Table 47 : The probability of interference for an FM mobile outside the area of a TETRA Direct Mode group

In this case the probabilities of interference fall to virtually zero. This means that for FM users not involved in a direct mode scenario the levels of interference will be dominated by Trunked TETRA radios rather than direct mode TETRA radios. This is due to the relatively low probability of being close by to a direct mode call.

6.2 TETRA DMO MS Interfering with an FM BS

For this scenario the FM base station may be either within or outside the area of the direct mode call but is not constrained to either. In Section 6.1 a scenario was considered where the FM mobile station was constrained to being within the area of the direct mode call coverage. This was to account for the scenario where possibly only one or two of the emergency services had upgraded to TETRA. This would lead to the scenario where possibly at the site of an accident there would be a mixture of TETRA and FM mobiles in the same coverage area. In the case of FM base stations there is no reason why base stations would always be within the area of the direct mode call. Only the scenario where the base stations are freely positioned inside and outside the direct mode coverage area is considered. The victim FM system is assumed to have a 7.8 km cell radius, which provides a 90 % area availability.

6.2.1 FM BS is inside or outside the area of the DMO call

The same channels are assumed as in Section 6.1.1 but with the base station receiving in the FM band. Simulations have been completed for all three direct mode scenarios. Table 48 presents the results.

Direct Mode Scenario	Probability of Interference to a 25 kHz FM BS	Probability of Interference to a 12.5 kHz FM BS
1	0.02 %	0.02 %
2	0..07 %	0.09 %
3	0.14 %	0.16 %

Table 48 : The probability of interference for an FM base station inside or outside the area of a TETRA Direct Mode group

The probabilities of interference are low. This means that the levels of interference for an FM base station will be dominated by Trunked TETRA radios rather than direct mode TETRA radios. This is due to the relatively low probability of being close by to a direct mode call. Nevertheless if an FM base station is within the area of a direct mode call frequency planning precautions should be taken.

7 DISCUSSION OF THE RESULTS

The results found in each section are summarized and dominant scenarios identified.

7.1 Non Co-sited TETRA and FM Systems

For this set of scenarios the TETRA and FM systems use separate masts for their base station antennas. Investigations were completed to determine the effects of interferer density, minimum carrier separation, band allocation size and power control. Table 49 and the bullet points below summarize the results. Two levels of interference are quoted from the body of the report. The first is for a typical scenario which would be encountered under normal operating conditions (2 active TETRA or FM mobile stations / km^2; 0.02 active TETRA base stations / km^2; 0.01 active FM base stations / km^2). The second is representative of a special case scenario where there are extraordinarily high active interferer densities. These may occur at some special events, for example at a large sports event (10 active TETRA or FM mobile stations / km^2; 0.20 active TETRA or FM base stations / km^2). Figures in parenthesis represent those obtained with additional base station transmit filtering.

Scenario	Typical Prob. of Interference	Special Case Prob. of Interference	Comments
TETRA MS to FM MS	0.15 %	0.50 %	high density of interferers; wanted signal from base; low antenna gains on victim / interferer link
TETRA MS to FM BS	1.65 %	4.74 %	high density of interferers; wanted signal from mobile; one high antenna gain on victim / interferer link
TETRA BS to FM MS	0.04 %	0.41 %	low density of interferers; wanted signal from base; one high antenna gain on victim / interferer link
TETRA BS to FM BS	3.29 % (0.75 %)	20.09 % (5.93 %)	low density of interferers; wanted signal from mobile; two high antenna gains on victim / interferer link. A Cavity Resonator can be used to reduce levels of interference
FM MS to TETRA MS	0.20 %	1.10 %	high density of interferers; wanted signal from base; low antenna gains on victim / interferer link
FM MS to TETRA BS	2.32 %	9.18 %	high density of interferers; wanted signal from mobile; one high antenna gain on victim / interferer link
FM BS to TETRA MS	0.01 %	0.15 %	low density of interferers; wanted signal from base; one high antenna gain on victim / interferer link
FM BS to TETRA BS	0.50 % (0.45 %)	8.12 % (7.32 %)	low density of interferers; wanted signal from mobile; two high antenna gains on victim / interferer link. A Cavity Resonator can be used to reduce levels of interference

Table 49 : Summary of the results for non co-sited TETRA and FM systems

For all scenarios :

- increasing the minimum carrier separation has marginal effect upon the average level of interference for the victim system but decreases the level of interference for the victim channel closest to the interfering system. In the former the level of interference, as estimated by the simulation, is insensitive to frequency planning because the result is an average of all frequency configurations.

- increasing the size of the allocated TETRA and FM bands from 2 MHz to 5 MHz has marginal effect upon the level of interference

- power control has a significant effect upon the level of interference typically reducing the probability of interference from between 20 % and 40 % depending upon the density of base stations belonging to the interfering system

- 12.5 kHz FM is slightly more susceptible to interference and causes slightly higher levels of interference relative to 25 kHz FM.

The dominant scenarios are those which involve mobile station to base station and base station to base station interference. In special case environments where the active user density is very high then additional measures may be required to maintain compatibility between TETRA and FM. This could be additional filtering in the base transmitter and receiver or frequency coordination between TETRA and FM operators. The figures in Table 49 show that the use of a cavity resonator can reduce TETRA base to FM base interference from 20 % to less than 6 %. The reduction is not so great when the same is applied to FM base to TETRA base interference because receiver blocking is more dominant. In this case additional filtering would be required in the TETRA base receiver.

7.2 Co-sited TETRA and FM Systems

For this set of scenarios the TETRA and FM systems share the same mast for their base station antennas. The same investigations as for the previous set of scenarios were completed. Table 50 and the bullet points below summarize the results.

Scenario	**Typical Prob. of Interference**	**Special Case Prob. of Interference**	**Comments**
TETRA MS to FM MS	0.19 %	0.84 %	interference greater than for non co-sited
TETRA MS to FM BS	0.43 %	1.76 %	interference lower than for non co-sited
TETRA BS to FM MS	0.00 %	0.00 %	interference lower than for non co-sited
TETRA BS to FM BS	dependent upon site engineering	Dependent upon site engineering	requires careful site engineering and placement of antennas upon mast; may require frequency coordination
FM MS to TETRA MS	0.20 %	1.10 %	identical to non co-sited due to no power control used by FM mobiles
FM MS to TETRA BS	2.32 %	9.18 %	identical to non co-sited due to no power control used by FM mobiles
FM BS to TETRA MS	0.00 %	0.00 %	interference lower than for non co-sited
FM BS to TETRA BS	dependent upon site engineering	Dependent upon site engineering	requires careful site engineering and placement of antennas upon mast; may require frequency coordination

Table 50 : Summary of the results for co-sited TETRA and FM systems

For all scenarios :

- increasing the minimum carrier separation has marginal effect upon the average level of interference for the victim system but decreases the level of interference for the victim channel closest to the interfering system
- increasing the size of the allocated TETRA and FM bands from 2 MHz to 5 MHz has marginal upon the level of interference
- power control has a significant effect upon the level of interference typically reducing the probability of interference from between 20 % and 40 % depending upon the density of base stations belonging to the interfering system
- 12.5 kHz FM is slightly more susceptible to interference and causes slightly higher levels of interference relative to 25 kHz FM.

Co-siting of base stations improves levels of interference in all scenarios except mobile station to mobile station. However the increase for this scenario is not significant and co-siting should be used if adequate isolation between TETRA and FM antennas can be achieved. Coordination of frequencies between system operators will make co-siting easier.

7.3 TETRA Direct Mode

For TETRA direct mode, three scenarios involving the emergency services are considered - a minor accident, moderate accident and major accident. The scenarios have an increasing number of active users spread across an increasing area. Table 51 and the bullet points below summarize the results.

Scenario	**Level of Interference**	**Comments**
TETRA DMO MS to FM MS - victim within area of DMO group	sc. 1 : 1.13 % sc. 2 : 2.27 % sc. 3 : 3.09 %	no power control leads to relatively high level of interference
TETRA DMO MS to FM MS - victim within or outside area of DMO group	sc. 1 : 0.00 % sc. 2 : 0.00 % sc. 3 : 0.01 %	interference from Trunked mode TETRA mobiles will dominate
TETRA DMO MS to FM BS - victim within or outside area of DMO group	sc. 1 : 0.02 % sc. 2 : 0.07 % sc. 3 : 0.14 %	interference from Trunked mode TETRA mobiles will dominate

Table 51 : Summary of the results for TETRA Direct Mode

For all scenarios :

- levels of interference are greatest for the major DMO scenario due to the higher density of interferers.

If an FM mobile is not directly involved in a direct mode scenario e.g. a taxi driver is not involved with a house fire, then the probability of interference due to direct mode TETRA radios is low. This is due to the low probability of being in the vicinity of the direct mode group. If however an FM mobile is involved in a scenario where direct mode TETRA is being used then levels of interference can be greater. This may occur if one of the emergency services e.g. the police service, upgrades to TETRA while the remaining emergency services continue to use FM.

8 CONCLUSIONS

The study has analyzed all interference scenarios between TETRA and FM including consideration of non co-sited systems, co-sited systems and TETRA direct mode. The following conclusions can be drawn for an allocation of TETRA channels adjacent to a set of analogue FM channels :

- under normal operating conditions TETRA and FM bands are able to coexist without guard bands in the same way that two FM operators are able to coexist without guard bands.

- in special circumstances where there is a very high density of active users e.g. security at a large sports event, then care must be taken to minimize levels of interference. Frequency coordination between TETRA and FM operators could help relieve any problems. Additional filtering in base station transmitters and receivers is also an effective method for controlling levels of interference.

- co-siting TETRA and FM base stations reduces levels of interference in all scenarios except mobile to mobile and of course base to base. Frequency coordination between TETRA and FM operators will make co-siting easier.

- TETRA direct mode does not cause high levels of interference to the general FM user. Levels of interference are greater for an FM user who is involved in the direct mode group e.g. at the scene of an accident where the police and fire services are using TETRA but the ambulance service is using FM. The introduction of power control in TETRA direct mode would alleviate any interference problems but simulations have not been completed to illustrate this.

Where coordination is required as systems are rolled out across Europe, it should be done on a case by case basis using site engineering practices.
This study provides simulation results for general 400 MHz TETRA and FM compatibility. Further work would be required to model specific scenarios within CEPT member states.

APPENDIX A

THE MONTE CARLO SIMULATION TOOL

The Monte Carlo simulation tool used for this study is based upon that specified by WG SE[3]. A general description is provided below followed by an explanation of some assumptions which are not explicitly stated in the WG SE specification.

A.1 General Description

A Monte Carlo simulation is a statistical technique that functions by considering many trials, that means many independent instants in time and many locations in space. For each simulation trial, a scenario is built up using a number of different random variables i.e. where the interferers are with respect to the victim, how strong the victim's wanted signal strength is, which channels the victim and interferer are using etc. If a sufficient number of trials are considered then the probability of a certain event occurring can be calculated with a high level of accuracy.

The Monte Carlo simulation used for this study, models a victim receiver operating amongst a population of interferers. The interferers are distributed around the victim using a uniform random distribution. Only a proportion of the interferers are active at any one time. Figure A1 illustrates how the interferers and victim may appear for one simulation trial.

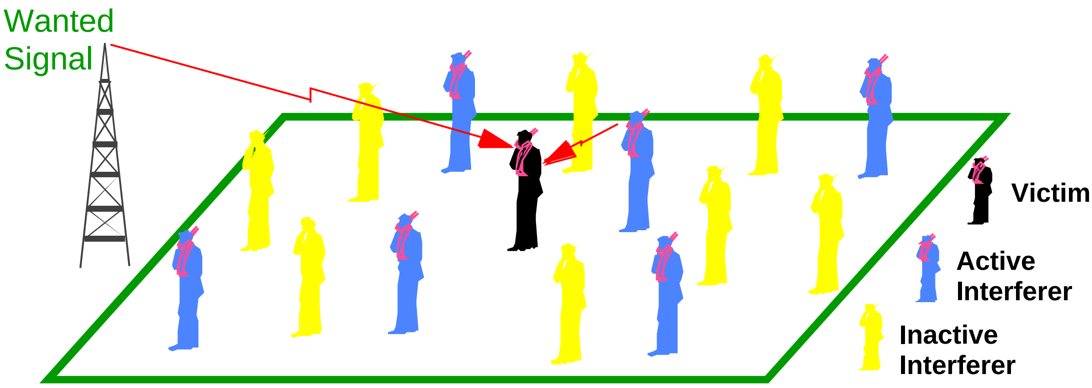

Figure A1 : An Illustration of the Monte Carlo Simulation Model

In general the effect of each interferer upon the victim is determined using mean path loss, slow fading, transmit power, antenna gains, transmitter wideband noise characteristic, receiver blocking and frequency separation. It can be found that for relatively low densities of interferers, for each trial one interferer dominates. This means that once the dominant interferer has been found then the remainder can be ignored without deeply affecting the final result. This means also that only one RF carrier is assumed to be active per interferer, so in the case that the BS are the interferers, the density of BS is equal to the density of sites and also to the density of active RF downlink carriers.

The victim’s wanted signal strength is calculated based upon the transmit power, antenna gains, mean path loss and slow fading.

Figure A1 illustrates a population of mobile stations interfering with a victim mobile. This is an example used for illustration purposes and in fact either or both the victim and interferers can be base stations.

The interfering power from the dominant interferer and wanted signal strength from the wanted signal transmitter are used to determine whether or not interference is occurring. Interference is said to occur when the resultant C/I is less than the protection ratio. Figure A2 illustrates the various signal levels.

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[3] CEPT ERC Report 68, Monte Carlo Radio Simulation Methodology,
http://www.ero.dk/eroweb/seamcat/seamcat.html

Interference is defined as occuring when the Resultant C/I is less than the C/I used to define Sensitivity

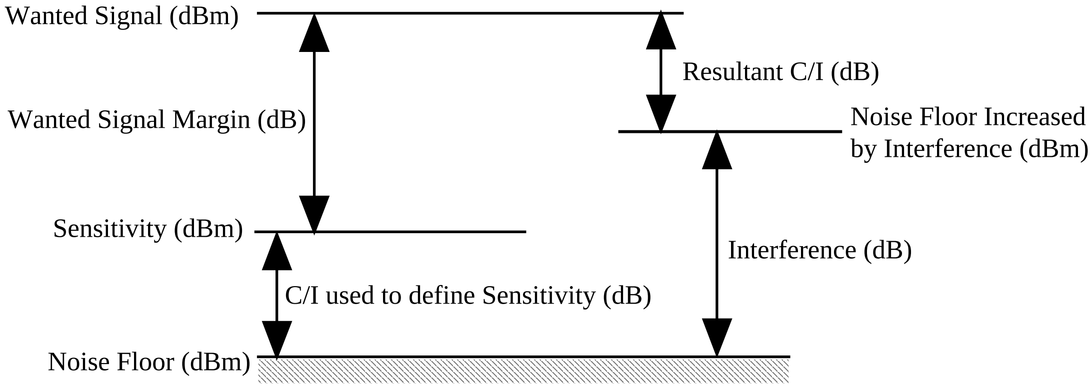

Figure A2 : The Signal Levels used to Determine Whether or Not Interference is Occurring

The left-hand side of the diagram represents the situation when there is no interference. In this case the resultant C/I ratio is equal to the sum of the protection ratio and the margin. The right hand side of the diagram illustrates what happens when interference is introduced. The interference may be caused by wideband noise or receiver blocking. The interference adds to the noise floor and the resultant C/I is the difference between the increased noise floor and the wanted signal strength. To avoid interference the resultant C/I must be greater than the protection ratio.

A.2 Specific Assumptions

The following sections provide an explanation to the aspects of the simulation methodology used in this study which may be different to that specified by Doc. SE(97)30.

A.2.1 Calculating the Victim's Receive Frequency

Two cases have been considered for this study. In the first, the victim radio system is allocated a block of channels and for each simulation trial the victim is assigned one channel using a uniform random distribution. In this case the probability result is in fact an average over the frequency set. In the second case, the victim system has only a single channel assigned and for each simulation trial the victim is assigned this channel.
When the victim is a base station, the level of interference calculated is for only one among the set of receivers at, the base station site. i.e. if a victim base station receives on four frequencies and has a probability of interference of 1 %, each of the four frequencies has a probability of interference of 1 %.

A.2.2 Calculating the interferers Transmit Frequency

The interfering radio system is allocated a block of channels and for each simulation trial the closest interferer is assigned one channel using a uniform random distribution. When the interferer is a base station, only one transmitter (i.e. one frequency) is assumed to be active, although this transmitter is assumed to transmit all the power of the base station.

A.2.3 Placing the Closest Interferer

A Rayleigh distribution is used to randomly place the closest interferer with respect to the victim. The density of active interferers is used to calculate the standard deviation of the Rayleigh distribution. When the victim and interferer are both base stations then a Rayleigh distribution is still used to place the closest interferer. This means that from one trial to the next the distance between base stations is not fixed modelling a range of possible separations. In this report the closest interferer has been considered in place of the dominant one. The closest interferer is not necessary the dominant one, but the closest has been considered for simplification reasons, the algorithm to determine the dominant being much more complicated because it has to take into account not only the distance but also the frequency separation, the shadowing, the transmit power etc... all these parameters being frequently random and to determine what is the dominant combination of them. Due to this simplification the results of the report could be considered as a little optimistic.

Moreover only the closest interferer is included in the interference calculation. The inclusion of other interferers increases simulation run time without significantly affecting the result. This has been found to be true for relatively low densities of interferers – as experienced in PMR scenarios. For simulations where high densities of interferers are modelled i.e. public cellular systems in hotspots, then all interferers must be considered due to the much higher possibility of a more distant interferer having greater influence due to the effects of fading.

A.2.4 Power Control

Power control may be used to reduce transmit power when there is a low path loss between transmitter and receiver. In this study power control has been used only for TETRA mobiles. Power control has not been used for base stations or FM mobiles - this is believed to reflect reality. Power control for TETRA mobiles is used only when TETRA is being considered as the interfering system. When TETRA is the victim system and for example a TETRA mobile is transmitting to a TETRA base station then power control is not considered. By doing so, simulation complexity and run time can be reduced without affecting the results. The results are not changed because a 20 dB margin above sensitivity has been assumed before power control is activated. Thus when power control is used then there is always at least 20 dB of wanted signal strength margin. In these cases there is a very low chance of interference occurring. Interference is more likely to occur when the wanted signal strength is relatively low and the margin is below 20 dB.

When power control is activated in the interfering system the corresponding cell radius has to be known to determine for each trial the position of the wanted receiver in the interfering system. When it is not activated the knowledge of the cell size is not required, only the interferers density is needed.

A.2.5 Path Loss

The path loss model for an outdoor urban area specified by WG SE in the Monte Carlo specification[4] has been used for this study. This path loss model is a combination of free space and Hata models. For distances below 40 m then free space propagation is assumed. For distances above 100 m then modified Hata propagation is assumed. Between these two limits the propagation loss is given by the interpolation between the free space loss at 40 m and the modified Hata loss at 100 m. The effect of shadowing is included using a lognormal distribution with standard deviation dependent upon distance.

A.2.6 Interference Mechanisms

This study has considered the effects of unwanted emissions and receiver blocking. These are believed to be the dominant interference mechanisms for compatibility between TETRA and FM.

A.2.7 Calculating the Wanted Signal Strength

The wanted signal strength is calculated based upon transmit power, path loss between transmitter and receiver and antenna gains. So the victim cell radius has to be known. In this report the radius values correspond to an intrinsic (only limited by receiver internal noise) ‘worst link’ area availability of 90 %. The wanted signal strength obtained is compared with the interfering signal strength as illustrated in Figure A.2 to determine whether or not the desired C/I ratio is being obtained.

A.2.8 Parameters used by the simulation

Channel Spacing - The channel bandwidth defined for the system i.e. the separation in frequency between adjacent carriers.

Transmit Power - The nominal transmit power.

Receiver Bandwidth - The bandwidth of the receiver. It may be less than the channel spacing dependent upon the filtering in the terminal’s receive path.

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[4] CEPT ERC Report 68, Monte Carlo Radio Simulation Methodology, http://www.ero.dk/eroweb/seamcat/seamcat.html

Antenna Height - The height of the antenna in metres.

Antenna Gain - Antennas in this study are assumed to have equal gain in all directions i.e. a spherical gain pattern. The value specified includes cable and connector losses.

Active Interferer Density Range - A range of interferer densities have been considered in this study to include a range of scenarios from what may be considered a 'hot spot' to what may be considered normal operating conditions.

Receiver Sensitivity - The sensitivity defined for the receiving terminal.

Receiver Protection Ratio - The protection ratio defines the number of dB between the thermal noise floor of the receiver and sensitivity.

TDMA users / carrier - The number of TDMA users that can simultaneously operate in the same geographic area on a single carrier. This parameter has an effect upon the interferer density being used by the simulation. When the interferers are TETRA mobile stations the probabilities of interference are estimated using an effective interferer density which is four times smaller than the active interferer density (taking into account the four slot TDMA implemented in TETRA.)

Power Control Characteristic - Specified by a step size, the number of steps and the threshold at which power control is activated. The threshold indicates the received signal level above which the receiver indicates to the transmitter that its power can be reduced. The amount by which it is reduced is determined by the margin above the threshold, the step size and the number of steps.

Unwanted Emissions Characteristic - The out-of-band emissions characteristic for a transmitter. Defined by a power measured in a specific bandwidth at a specific frequency offset from the nominal transmit frequency.

Receiver Blocking Characteristic - The receiver blocking performance defined by a power level at a specific frequency offset which the receiver can sustain which receiving its wanted signal 3 dB above sensitivity.

A.3 Interpretation of the Results

The probability of interference evaluated is the probability of a victim receiver not obtaining its desired C/I requirement. It can be thought of as a reduction of the system area availability.

A radio system may have an area availability of 90 % meaning that either over 10 % of the area, coverage is not provided or that for 10 % of the time a user will be out of coverage (assuming the user to move around the cell occupying both outer and inner cell positions). Likewise the probability of interference can be interpreted in this way and a 1 % probability of interference would reduce a 90 % area availability to 89.1 %.

The probability of interference is the probability for a single receive channel. In the case of a base station where multiple channels are being used then the probability is that for each channel considered in isolation. In the same way, when the interferers are base stations, it is assumed that only one interfering RF carrier is activated per base station and per trial. This RF carrier is assumed to be active 100 % of the time.

It should be kept in mind that in the case of group calls interference to a single base station channel can affect the reception of multiple mobile stations.

APPENDIX B

PARAMETERS USED FOR SIMULATION

B.1 TETRA

The ETSI standard ETS 300 392-2 has been used to obtain most of the TETRA system parameters. This standard is titled 'Radio Equipment and Systems (RES); Trans-European Trunked Radio (TETRA); Voice plus Data (V+D); Part 2: Air Interface (AI)'. Those parameters which cannot be obtained from the standard are assumed values believed to accurately model operational TETRA systems. Tables B1, B2 and B3 list all of the parameters required by the Monte Carlo simulation to model a TETRA system.

Parameter	**Mobile Station**	**Base Station**
Channel Spacing	25 kHz	25 kHz
Transmit Power	30 dBm, 35 dBm, 40 dBm	40 dBm
Receiver Bandwidth	18 kHz	18 kHz
Antenna Height	1.5 m	30 m
Antenna Gain	0 dBi	9 dBi (12 dBi - 3 dB)
Active Interferer Density Range	Variable	variable
Receiver Sensitivity	- 103 dBm	- 106 dBm
Receiver Protection Ratio	19 dB	19 dB
TDMA Users / carrier	4	4
Power Control Characteristic	5 dB steps to a minimum of 15 dBm. Threshold = - 86 dBm	not used

Table B1 : Parameters used to model the TETRA System

Frequency Offset	**30 dBm Mobile Station**	**35 dBm Mobile Station**	**40 dBm Mobile Station**	**40 dBm Base Station**
25 kHz	- 30 dBm	- 25 dBm	- 20 dBm	- 20 dBm
50 kHz	- 36 dBm	- 35 dBm	- 30 dBm	- 30 dBm
75 kHz	- 36 dBm	- 35 dBm	- 30 dBm	- 30 dBm
100 - 250 kHz	- 45 dBm	- 43 dBm	- 40 dBm	- 40 dBm
250 - 500 kHz	- 50 dBm	- 48 dBm	- 45 dBm	- 45 dBm
500 kHz - f_{rb}	- 50 dBm	- 50 dBm	- 50 dBm	- 50 dBm
> f_{rb}	- 70 dBm	- 65 dBm	- 60 dBm	- 60 dBm
At frequency offsets less than 100 kHz no limit tighter than - 36 dBm shall apply At frequency offsets equal to and greater than 100 kHz no limit tighter than - 70 dBm shall apply				

Table B2 : Unwanted Emissions for the TETRA System (measurement bandwidth of 18 kHz)

Frequency Offset	**30, 35, 40 dBm Mobile Station**	**40 dBm Base Station**
50 - 100 kHz	- 40 dBm	- 40 dBm
100 - 200 kHz	- 35 dBm	- 35 dBm
200 - 500 kHz	- 30 dBm	- 30 dBm
> 500 kHz	- 25 dBm	- 25 dBm

Table B3 : Receiver Blocking for the TETRA System

B.2 25 kHz FM

The ETSI standards ETS 300 086 and ETS 300 113 have been used to obtain information regarding 25 kHz FM system parameters. Other parameters are assumed values believed to accurately model operational FM systems. Tables B4, B5 and B6 list all of the parameters required by the Monte Carlo simulation to model a 25 kHz FM system.

Parameter	Mobile Station	Base Station
Channel Spacing	25 kHz	25 kHz
Transmit Power	37 dBm	44 dBm
Receiver Bandwidth	15 kHz	15 kHz
Antenna Height	1.5 m	30 m
Antenna Gain	0 dBi	9 dBi
Active Interferer Density Range	Variable	variable
Receiver Sensitivity	- 107 dBm	- 110 dBm
Receiver Protection Ratio	17 dB	17 dB
Power Control Characteristic	not used	not used

Table B4 : Parameters Assumed for 25 kHz FM Systems

Frequency Offset	Mobile Station	Base Station
25 kHz	- 33 dBm	- 26 dBm
100 - 250 kHz	- 53 dBm	- 46 dBm
250 - 500 kHz	- 60 dBm	- 53 dBm
500 kHz - 1 MHz	- 64 dBm	- 57 dBm
1 MHz - 10 MHz	- 69 dBm	- 62 dBm
> 10 MHz	- 71 dBm	- 64 dBm
Linear interpolation (in dB) is used between 25 kHz and 100 kHz		

Table B5 : Unwanted Emissions for 25 kHz FM Systems (measurement bandwidth of 18 kHz)

Frequency Offset	Mobile Station	Base Station
any frequency	- 23 dBm	- 23 dBm

Table B6 : Receiver Blocking for 25 kHz FM Systems

B.3 20 kHz FM

The ETSI standards ETS 300 086 and ETS 300 113 have been used to obtain information regarding 20 kHz FM system parameters. Other parameters are assumed values believed to accurately model operational FM systems. Tables B7, B8 and B9 list all of the parameters required by the Monte Carlo simulation to model a 20 kHz FM system.

Parameter	Mobile Station	Base Station
Channel Spacing	20 kHz	20 kHz
Transmit Power	37 dBm	44 dBm
Receiver Bandwidth	12 kHz	12 kHz
Antenna Height	1.5 m	30 m
Antenna Gain	0 dBi	9 dBi
Active Interferer Density Range	Variable	variable
Receiver Sensitivity	- 107 dBm	- 110 dBm
Receiver Protection Ratio	17 dB	17 dB
Power Control Characteristic	not used	not used

Table B7 : Parameters Assumed for 20 kHz FM Systems

Frequency Offset	Mobile Station	Base Station
20 kHz	- 33 dBm	- 26 dBm
100 - 250 kHz	- 53 dBm	- 46 dBm
250 - 500 kHz	- 60 dBm	- 53 dBm
500 kHz - 1 MHz	- 64 dBm	- 57 dBm
1 MHz - 10 MHz	- 69 dBm	- 62 dBm
> 10 MHz	- 71 dBm	- 64 dBm
Linear interpolation (in dB) is used between 20 kHz and 100 kHz		

Table B8 : Unwanted Emissions for 20 kHz FM Systems (measurement bandwidth of 12 kHz)

Frequency Offset	Mobile Station	Base Station
any frequency	- 23 dBm	- 23 dBm

Table B9 : Receiver Blocking for 20 kHz FM Systems

B.4 12.5 kHz FM

The ETSI standards ETS 300 086 and ETS 300 113 have been used to obtain information regarding 12.5 kHz FM system parameters. Other parameters are assumed values believed to accurately model operational FM systems. Tables B10, B11 and B12 list all of the parameters required by the Monte Carlo simulation to model a 12.5 kHz FM system.

Parameter	Mobile Station	Base Station
Channel Spacing	12.5 kHz	12.5 kHz
Transmit Power	37 dBm	44 dBm
Receiver Bandwidth	8 kHz	8 kHz
Antenna Height	1.5 m	30 m
Antenna Gain	0 dBi	9 dBi
Active Interferer Density Range	Variable	variable
Receiver Sensitivity	- 107 dBm	- 110 dBm
Receiver Protection Ratio	21 dB	21 dB
Power Control Characteristic	not used	not used

Table B10 : Parameters Assumed for 12.5 kHz FM Systems

Frequency Offset	Mobile Station	Base Station
12.5 kHz	- 23 dBm	- 16 dBm
100 - 250 kHz	- 43 dBm	- 36 dBm
250 - 500 kHz	- 60 dBm	- 53 dBm
500 kHz - 1 MHz	- 64 dBm	- 57 dBm
1 MHz - 10 MHz	- 69 dBm	- 62 dBm
> 10 MHz	- 71 dBm	- 64 dBm
Linear interpolation (in dB) is used between 12.5 kHz and 100 kHz		

Table B11 : Unwanted Emissions for 12.5 kHz FM Systems (measurement bandwidth of 8 kHz)

Frequency Offset	Mobile Station	Base Station
Any frequency	- 23 dBm	- 23 dBm

Table B12 : Receiver Blocking for 12.5 kHz FM Systems

APPENDIX C

ABBREVIATIONS

BS	Base Station
CEPT	European Conference of Posts and Telecommunications Administrations
DMO	Direct Mode Operation
ERC	European Radio Commission
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
FM	Frequency Modulation
MS	Mobile Station
PAMR	Public Access Mobile Radio
PMR	Private (or Professional) Mobile Radio
PT	Project Team
RES	Radio Equipment and Systems
SE	Spectrum Engineering
TDMA	Time Division Multiple Access
TETRA	Terrestrial Enhanced Trunked Radio